AEDC-TSR-82-V38

PA: 8 Feb 83
Request clearance for public release. Test was sponsored by NASA/MSFC/EP44 /W. P. Baker, Huntsville, AL
F. O. Cole

WIND TUNNEL TESTS OF SPACE SHUTTLE SOLID ROCKET BOOSTER INSULATION MATERIAL IN THE AEROTHERMAL TUNNEL C

A. S. Hartman and K. W. Nutt
Calspan Field Services, Inc.

AEDC/PA 83-20

(AEDC-TSR-82-V38) WIND TUNNEL TESTS OF SPACE SHUTTLE SOLID ROCKET BOOSTER INSULATION MATERIAL IN THE AEROTHERMAL TUNNEL C Final Report, 2 Sep. - 22 Sep. 1982 (Calspan Field Services, Inc.) 54 p H2/20

N83-19808

Unclas 03049

November 1982

Final Report for Period 2 September 1982 to 11 September 1982

Not cleared for public release without prior written approval of NASA/MSFC/EP44, Marshall Space Flight Center, Huntsville, AL 35812.

ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

ORIGINAL PAGE IS
OF POOR QUALITY

APPROVAL STATEMENT

This report has been reviewed and approved.

J. T. Best

J. T. BEST
Aeronautical Systems Branch
Deputy for Operations

Approved for publication:

FOR THE COMMANDER

J M Rampy

JOHN M. RAMPY, Director
Aerospace Flight Dynamics Test
Deputy for Operations

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ORIGINAL PAGE IS OF POOR QUALITY

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AEDC-TSR-82-V38	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) WIND TUNNEL TESTS OF SPACE SHUTTLE SOLID ROCKET BOOSTER INSULATION MATERIAL IN THE AEROTHERMAL TUNNEL C		5. TYPE OF REPORT & PERIOD COVERED Final Report Sept. 2 - Sept. 22, 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. S. Hartman and K. W. Nutt Calspan Field Services, Inc./AEDC Division		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Arnold Engineering Development Center Air Force Systems Command Arnold Air Force Station, TN 37389		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 921E02 Control No. 9E02
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE November 1982
		13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Not cleared for public release without prior written approval of NASA/MSFC/EP44, Marshall Space Flight Center, Huntsville, AL 35812.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

space shuttle
External Tank
aerodynamic heating
materials testing
heat transfer
foam insulation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Wind tunnel tests of the space shuttle Solid Rocket Booster Insulation were conducted in the von Karman Gas Dynamics Facility Tunnel C. For these tests, Tunnel C was run at Mach 4 with a total temperature of 1100-1440 °F and a total pressure of 100 psia. Cold wall heating rates were changed by varying the test article support wedge angle. Selected results are presented to illustrate the test techniques and typical data obtained.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ORIGINAL PAGE IS OF POOR QUALITY

CONTENTS

APPENDIXES

I. ILLUSTRATIONS

II. TABLES

III. SAMPLE TABULATED AND PLOTTED DATA

NOMENCLATURE

ALPHI	Indicated pitch angle, deg
b, THICK	Calibration plate skin thickness, in.
c	Calibration plate material specific heat, $Btu/ft^2/lbm-°R$
C1	Laboratory gage calibration factor, Btu/ft^2-sec-mv
C2	Temperature corrected gage calibration factor, Btu/ft^2-sec-mv
CAL	Calibration
CAMERA	Denotes camera locations: TOP - top of tunnel, OS - operating side of tunnel (right side looking downstream) SHG - Shadowgraph, IR - Infrared monitor screen)
CP	Free-stream specific heat, Btu/lbm-°R
CR	Center of rotation, axial station along the tunnel centerline about which the model rotates in pitch, in.
DTW/DT	Derivative of the model wall temperature with respect to time, °R/sec
E	Gardon gage output, mv
fps	Frames per sec
GAGE	Gardon gage identification number
H(TRT)	Heat transfer coefficient based on the theoretical recovery temperature for turbulent flow (TRT), QDOT/(TRT-TW), Btu/ft^2-sec-°R
H(TT)	Heat transfer coefficient based on TT, QDOT/(TT-TW), Btu/ft^2-sec-°R
ITT	Enthalpy based on TT, Btu/lbm
KG	Gardon gage temperature calibration factor, °R/mv
M	Free-stream Mach number
MU	Dynamic viscosity based on free-stream temperature, lbf-sec/ft^2

ORIGINAL PAGE IS
OF POOR QUALITY

P	Free-stream static pressure, psia
PIC NO	Picture number, corresponds to number on each frame of contact print XXXX - XXX RUN NUMBER FRAME NUMBER
PT	Tunnel stilling chamber pressure, psia
Q	Free-stream dynamic pressure, psia
QDOT	Heat flux, Btu/ft^2-sec
QDOT-0	Cold wall (i.e., 0°F) heat flux calculated from QDOT = H(TT)(TT-460), Btu/ft^2-sec
RE	Free-stream Reynolds number, ft^{-1}
RHO	Free-stream density, lbm/ft^3
ROLL NO	Identification number for each roll of film
RUN	Data set identification number
SAMPLE	Specimen number
ST	Stanton number based on TT and free stream conditions, H(TT)/(RHO*V*CP)
STREX.2	Heat transfer correlation parameter ST(RE*X)$^{0.2}$
T	Free-stream static temperature, °R
T/C	Thermocouple identification number
TGE	Gardon gage edge temperature, °R
TGDEL	Temperature differential from the center to the edge of Gardon gage disc, °R
TI	Initial wall temperature
TIME	Elapsed time from lift-off, sec
TIMECL	Time at which the model reached tunnel centerline, Central Standard Time

ORIGINAL PAGE IS
OF POOR QUALITY

TIMEEXP	Time of exposure to the tunnel flow when the data were recorded, [TIME - $\frac{32}{57}$ (TIMEINJ)], sec
TIMEEXPT	Total exposure time for a RUN, sec
TIMEINJ	Elapsed time from lift-off to arrival at tunnel centerline, sec
TP	Wedge plate temperature, °R
TS	Material sample thermocouple temperature, °R
TT	Tunnel stilling chamber temperature, °R
TW	Model surface temperature, °R
V	Free-stream velocity, ft/sec
WA	Wedge angle deg (see Fig. 3)
X, Y, Z	Orthogonal body axis system directions (see Fig. 3)
ε	Specimen emissivity
ρ	Calibration plate material density

1.0 INTRODUCTION

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E02, Control Number 9E02, at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), Huntsville, Alabama for Lockheed Missile and Space Co., Huntsville, AL. The Lockheed Missile and Space Co. project engineer was Mr. B. Dean and the NASA/MSFC project manager was Mr. W. P. Baker. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was performed in the von Karman Gas Dynamics Facility (VKF), Hypersonic Wind Tunnel (C), on September 2, 21 and 22, 1982 under AEDC Project No. C462VC (Calspan No. V41-C-2K).

The objective of this test was to measure the response to convective heating of the material used on the space shuttle's Solid Rocket Booster (SRB) Thermal Protection System (TPS). The wedge technique was used to produce local heating rates (Ref. 1) on the test sample.

Data were recorded at Mach number 4 with a tunnel stilling chamber pressure of 100 psia at stilling chamber temperatures of 1560-1900°R (1100-1440°F). Cold wall heating rates of nominally 4 to 20 Btu/ft^2-sec were obtained by varying the wedge angle (WA).

All test data including detailed logs and other information required to use the data have been transmitted [redacted] as described in Table 1. Inquiries to obtain copies of the test data should be directed to NASA/MSFC/EP44, Marshall Space Flight Center, Huntsville, Alabama, 35812. A microfilm record has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

The Mach 4 Aerothermal Tunnel C is a closed-circuit, high temperature, supersonic free-jet wind tunnel with an axisymmetric contoured nozzle and a 25 in.-diam nozzle exit, Fig. 1. This tunnel utilizes parts of the Tunnel C circuit (the electric air heater, the Tunnel C test section and injection system) and operates continuously over a range of pressures from nominally 15 psia at a minimum stagnation temperature of 710°R to 180 psia at a stagnation temperature of 1570°R. Using the normal Tunnel C Mach 10 circuit (Series Heater Circuit), the Aerothermal Mach 4 nozzle operates at a maximum pressure and temperature of 100 psia and 1900°R, respectively. The air temperatures and pressures are normally achieved by mixing high temperature

air (up to 2250°R) from the primary flow discharged from the electric heater with the bypass air flow (at 1440°R) from the natural gas-fired heater. The primary and the bypass air flows discharge into a mixing chamber just upstream of the Aerothermal Tunnel C stilling chamber. The entire Aerothermal nozzle insert (the mixing chamber, throat and nozzle sections) is water cooled by integral, external water jackets. Since the test unit utilizes the Tunnel C model injection system, it allows for the removal of the model from the test section while the free-jet tunnel remains in operation. A description of the Tunnel C equipment may be found in the Test Facilities Handbook, Ref. 2.

2.2 TEST ARTICLE

The test article was designed to simulate the flow conditions over a section of material used on the SRB-TPS. To provide the desired flow conditions over the material, the wedge technique developed for material testing was used (Ref. 1). The oblique shock wave generated by the wedge reduces the free stream flow properties to the desired flow conditions. The flow field conditions over the wedge can be controlled by changing the wedge angle and, if desired, by adjusting the tunnel stilling chamber conditions.

The test article was supported by a sting which was attached to the Tunnel "C" mounting hardware. An installation photograph and sketch of the fixture in Tunnel C are shown in Fig. 2. The test article was comprised of two parts (the basic wedge and interchangeable material specimens) and is shown in Fig. 3. The wedge was 12 in. wide x 34 in. long. Three rows of 0.032 in. diam boundary layer trip spheres were attached to the wedge as shown in Fig. 3. A thin-skin calibration plate was used to obtain heat transfer levels at the higher wedge angles. This plate is shown in Fig. 4.

A typical test specimen consisted of a 12 in. x 10 in. x 0.125 in. aluminum support plate covered with a 1.0 ± 0.25 in. layer of Instafoam® or a varying thickness of MSA2®. Examples of pretest and posttest photographs of the material specimens are shown in Fig. 5. For a complete list of material specimens see Table 2. All but two samples had imbedded thermocouples. The locations of these thermocouples are unavailable for this report.

2.3 TEST INSTRUMENTATION

The instrumentation, recording devices, and calibration methods used to measure the primary tunnel and test data parameters are listed in Table 3a along with the estimated measurement uncertainties. The range and estimated uncertainties for primary parameters that were calculated from the measured parameters are listed in Table 3b.

A variety of cameras was used to record the test results. Color motion pictures and 70mm sequence color stills recorded any changes in the samples as they were tested. These movie cameras were operated at frame rates of 24 fps. A shadowgraph still was taken for each run. A black and white video tape was also made for general coverage during the tests. Color 70mm sequence photographs and 16mm color movies (∿ 8 fps) were taken of the IR monitor. All photographic data taken during the test are identified in Table 4.

The Gardon gages used in the wedge were a special high temperature type, 0.25-in. diam, with a 0.010-in. thick sensing disk. Each gage had a Chromel®-Alumel® thermocouple to provide the gage edge temperature. These temperatures, together with the gage output, were used to determine the gage surface temperatures and corresponding heat transfer rate, which was then used to calculate the local heat transfer coefficient. The coordinate locations of the Gardon gages are listed in Table 5a.

The calibration plate temperatures were measured with FE-CN thermocouples. The thermocouple locations are shown in Fig. 4 and their coordinates and corresponding skin thickness are listed in Table 5b.

The infrared system which was used to measure model surface temperatures utilizes an AGA Thermovision® 680 camera which scans at the rate of 16 frames per second. The camera has a detector which is sensitive to infrared radiation in the 2 to 6 micron wavelength band. A description of the system is given in Ref. 3.

A total time of exposure to the tunnel flow is also required for data reduction. All the events which occur during a run, except the IR data, are timed using the digital clock in the DEC-10 computer, which processes all data from the continuous tunnels. The IR system used its own internal clock to reduce its time of exposure used in the IR data.

The imbedded thermocouples used to record temperature histories at various points inside the insulation materials were installed by Lockheed during specimen fabrication. Exact locations were not available for this report.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS

A summary of the nominal test conditions is given below:

Date	M	PT, psia	TT, °R	RUNS
Sept. 2, 1982	3.92	100	1560-1900	1-27
Sept. 21, 1982	3.92	100	1560	28-30
Sept. 22, 1982	3.92	100	1560-1900	31-72

ORIGINAL PAGE IS
OF POOR QUALITY

A test summary showing the configurations tested and the variables for each is presented in Table 6.

3.2 TEST PROCEDURES

In the VKF continuous flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, the model is injected into the airstream, and the fairing doors are closed. After the data are obtained, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. The sequence is repeated for each configuration change.

The required local flow conditions over the test specimens are produced by attaching the panel to a large wedge. A complete description of this technique as used in Tunnel C is given in Ref. 1.

Instrumentation outputs were recorded using the digital data scanner in conjunction with the analog subsystem. Data acquisition from all instruments other than the infrared camera was under the control of a Digital Equipment Corporation (DEC) PDP 11/40 computer, utilizing the random access data system (RADS). The data were transmitted to a DEC-10 computer for processing.

During a run, the AGA 680 infrared camera scanned the model to produce a complete picture at the rate of 16 frames per second. The camera output was recorded on analog tape and simultaneously displayed on a color television monitor. The developing color patterns were observed as the model surface temperature increased, and the monitor was photographed as described in Section 2.3 to provide a permanent record. The camera output was also fed to an analog-to-digital converter under the cont ol of a PDP 11/34 computer. A single complete frame was digitized and transmitted to the DEC-10 computer at a rate predetermined for this test. During the first night of testing the PDP 11-34 was unable to transmit data to the DEC-10. The Runs were recorded on magnetic tape and retrieved later. These Runs are listed in Table 6.

Model attitude positioning and data recording were accomplished in one of two ways for each model injection. For most runs, the model attitude was set while in the installation tank and the model was injected at that attitude with data recorded automatically at preselected time intervals. For two runs, the model was pitched using the sweep mode of operation under the control of the Model Attitude Control System (MACS). With the MACS, model pitch requirements were entered into the controlling computer prior to the test and model positioning was performed automatically by the system. The requested and actual trajectories are compared in Fig. 6.

3.3 DATA REDUCTION

Measured stilling chamber pressure and temperature and the calibrated test section Mach number are used to compute the free-stream parameters. The equations for a perfect gas isentropic expansion from stilling chamber to test section were modified to account for real gas effects.

Data measurements obtained from the Gardon gages are gage output (E) and gage edge temperature (TGE). The gages are direct reading heat flux transducers and the gage output is converted to heating rate by means of a laboratory calibrated gage scale factor (C1). The scale factor has been found to be a function of gage temperature and therefore must be corrected for gage temperature changes,

$$C2 = C1\ f(TGE) \tag{1}$$

Heat flux to the gage is then calculated for each data point by the following equation:

$$QDOT = (E)(C2) \tag{2}$$

The gage wall temperature used in computing the gage heat-transfer coefficient is obtained from two measurements - the output of the gage edge thermocouple (TGE) and the temperature difference (TGDEL) from the gage center to its edge. TGDEL is proportional to the gage output, E, and is calculated by:

$$TGDEL = (KG)(E) \tag{3}$$

The gage wall temperature is then computed as

$$TW = TGE + 0.75(TGDEL) \tag{4}$$

where the factor 0.75 represents the average value across the gage.

The standard Gardon gage data reduction procedure was used to compute model local heat transfer-coefficients. The procedure averages five consecutive samples of gage output (E), commencing with the data loop recorded at approximately the time the model arrives at tunnel centerline. The gage edge temperature (TGE) was averaged in the same manner.

The heat transfer coefficient for each gage was computed using the following equation,

$$H(TT) = \frac{QDOT}{(TT-TW)} \tag{5}$$

QDOT-0 is the heat flux calculated when the gage wall temperature (TW) is assumed to be 460°R (0°F). It is computed using the following equation,

$$QDOT\text{-}0 = H(TT)(TT-460) \tag{6}$$

The reduction of thin skin temperature data to coefficient form normally involves only the calorimeter heat balance for the thin skin as follows:

$$QDOT = \rho bc\ DTW/DT \tag{7}$$

$$H(TT) = \frac{QDOT}{TT-TW} = \frac{\rho bc\ DTW/DT}{TT-TW} \tag{8}$$

Thermal radiation and heat conduction effects on the thin-skin element are neglected in the above relationship and the skin temperature response is assumed to be due to convective heating only. It can be shown that for constant TT, the following relationship is true:

$$\frac{d}{dt} \ln \left[\frac{TT-TI}{TT-TW}\right] = \frac{DTW/DT}{TT/TW} \tag{9}$$

Substituting Eq. (9) in Eq. (8) and rearranging terms yields:

$$\frac{H(TT)}{\rho bc} = \frac{d}{dt} \ln \left[\frac{TT-TI}{TT-TW}\right] \tag{10}$$

By assuming that the value of $H(TT)/\rho bc$ is a constant, it can be seen that the derivative (or slope) must also be constant. Hence, the term

$$\ln \left[\frac{TT-TI}{TT-TW}\right]$$

is linear with time. This linearity assumes the validity of Eq. (8) which applies for convective heating only. The evaluation of conduction effects will be discussed later.

The assumption that H(TT) and c are constant is reasonable for this test although small variations do occur in these parameters. The variations of H(TT) caused by changing wall temperature and by transition movement with wall temperature are trivial for the small wall temperature changes that occur during data reduction. The value of the model material specific heat, c, was computed by the relation

$$c = 8.86196 \times 10^{-2} + 3.98668 \times 10^{-5}(TW), \text{ (316 stainless steel)} \quad (11)$$

The maximum variation of c over any curve fit was less than 1.5 percent. Thus, the assumption of constant c used to derive Equation 10 was reasonable. The value of density used for the 316 stainless steel skin was, $\rho = 501 \text{ lbm/ft}^3$, and the skin thickness, b, for each thermocouple is listed in Table 5.

The right side of Equation 10 was evaluated using a linear least squares curve fit of 7 consecutive data points to determine the slope. The curve fit was started at approximately the time the model arrived on the tunnel centerline. For each thermocouple the tabulated value of H(TT) was calculated from the slope and the appropriate values of ρbc; i.e.,

$$H(TT) = \rho bc \frac{d}{dt} \ln \left[\frac{TT-TI}{TT-TW}\right] \quad (12)$$

To investigate conduction effects a second value of H(TT) was calculated at a time one second later. A comparison of these two values was used to identify those thermocouples that were influenced by significant conduction (or system noise). Conduction and/or noise effects were found to be negligible.

As discussed in Section 3.2, the output of the IR camera is displayed in real time on a color television monitor. A 70-mm camera was used to photograph the monitor screen simultaneously with the single frame digitizing process. An example of a monitor screen photograph is given in Fig. 7. On the television monitor the total-temperature range which the system is set up to measure is divided, in a nonlinear fashion, into ten separate colors, starting with blue for the lowest temperature and progressing through white for the highest. Each color then represents a temperature band within the total range, and the interface between two colors corresponds to one particular temperature. This provides a view in which unusual temperature patterns would be more easily discerned than in the digital data tabulations.

Digital infrared data were obtained at the rate listed on Table 6. One complete frame of infrared data consists of 70 scan lines with 110 points per line for a total of 7700 discrete but overlapping spots. For most test installations the field-of-view is such that the model does not fill the complete frame. In order to save storage space in the computer, only the portion of the frame which contains good model data is digitized. For this test the area of interest was 27 lines by 67 points (1809 discrete spots). For each spot, the camera output

is digitized and converted to a temperature reading by means of an equation derived from basic laws of radiation and incorporating various constants peculiar to this system. These constants are obtained from laboratory calibrations using a standard black body source. The calculated temperatures were nondimensionalized using the tunnel stilling chamber temperature. The ratios were tabulated in a two-dimensional array in which each spot location is defined by its Line number and Point number. The temperature given is the integrated temperature from an area approximately 1.2 in. in diameter. The IR data were reduced using a model emissivity of 0.9. Care must be used in selecting correct emissivity as errors in temperature can be introduced due to an emissivity mismatch. Figure 8 shows the corrections needed for two different wall temperatures.

In order to use the IR data it is necessary to define the model position in terms of Line and Point number. This was done by taking wind-off infrared scans of the wedge, with specimens attached, in the tunnel at the test attitude. The wedge, test panel, and tunnel walls were all at a uniform temperature equal to the room temperature. However, the test panel had a much higher emissivity than the other components. Thus, it was possible to adjust the system sensitivity so that the test panel could be seen in one color against a different colored background. A marker is then superimposed on the video monitor by the IR system electronics. This marker is a matrix of dots representing each spot in the digitized IR data. The marker can be controlled so that individual Lines or Points may be identified, or areas may be defined.

Figure 7 shows an IR photograph and its orientation in the tunnel. Lines and points of the leading edge and the trailing edge of the sample are shown for various wedge angles. Figure 9 shows a comparison of an IR photograph and a 70-mm top sequence photograph.

The above discussion implies that a given point on the model can be located within plus or minus one IR Line or Point. This dimension is a function of the camera detector size, the camera optics, and the distance to the model. For this test these parameters were such that the accuracy with which a given point on the model can be located within the IR frame was approximately 0.35 in.

For some runs, two sets of IR data photographs exist. The first set of photographic data was taken on shift and corresponds to the time shown in the tabulated photographic data (see Appendix III). The second set of photographic data was taken during the play back of the magnetic tape. The time shown on the second set of photographs is accurate to ±5.0 sec and may not correspond to the times shown on the tabulated IR data. The times to be used to utilize all photographic data from the magnetic tape should come from the tabulated IR DATA. The times shown on all tabulated data are accurate to ±0.04 sec. Table 4 identifies all rolls of film.

3.4 UNCERTAINTY OF MEASUREMENTS

In general, instrumentation calibrations and data uncertainty estimates were made using methods recognized by the National Bureau of Standards (NBS). Measurement uncertainty is a combination of bias and precision errors defined as:

$$U = \pm(B + t_{95}S)$$

where B is the bias limit, S is the sample standard deviation and t_{95} is the 95th percentile point for the two-tailed Student's "t" distribution (95-percent confidence interval), which for sample sizes greater than 30 is taken equal to 2.

Estimates of the measured data uncertainties for this test are given in Table 3a. The data uncertainties for the measurements are determined from in-place calibrations through the data recording system and data reduction program.

Propagation of the bias and precision errors of measured data through the calculated data was made in accordance with Ref. 4 and the results are given in Table 3b.

4.0 DATA PACKAGE PRESENTATION

A complete set of all photographic data and tabulated data for this test has been provided to Lockheed Missile and Space Co. Photographic data which showed significant testing results and a complete set of tabulated data have been provided to NASA/Marshall Space Flight Center/EP44, Huntsville, Alabama. All test specimens for this test have been returned to the Lockheed Missile and Space Co.

Samples of the tabulated and plotted data from the calibration and materials specimen runs are presented in Appendix III. A copy of all tabulated data has been retained on microfilm in the VKF.

Agreement of the test data to a flat plate solution using the Echert reference method was good and an example can be seen in Fig. 10. Data repeatability from run to run was excellent and an example can be seen in Fig. 11.

REFERENCES

1. Matthews, R. K. and Stallings, D. W. "Materials Testing in the VKF Continuous Flow Wind Tunnels," presented at AIAA 9th Aerodynamic Testing Conference, Arlington, TX, June 7-9, 1976.

2. Test Facilities Handbook (Eleventh Edition). "von Karman Gas Dynamics Facility, Vol. 3." Arnold Engineering Development Center, April 1981.

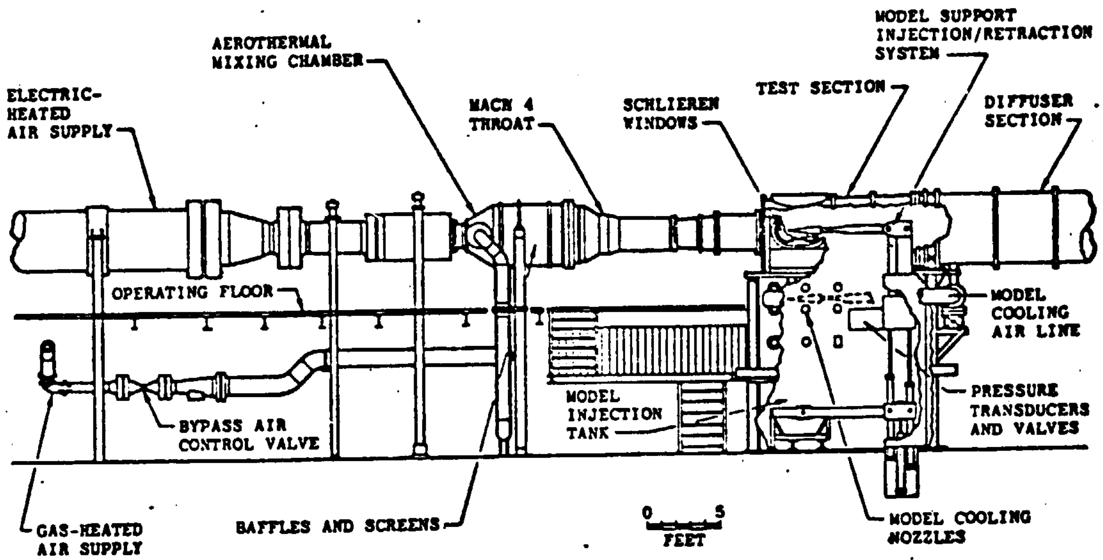
3. Boylan, D. E., Carver, D. B., Stallings, D. W., and Trimmer, L. L. "Measurement and Mapping of Aerodynamic Heating Using a Remote Infrared Scanning Camera in Continuous Flow Wind Tunnels," AIAA Preprint 78-799, April 1978.

. Thompson, J. W. and Abernethy, R. B. et. al., "Handbook Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5 (AD755356) February 1973.

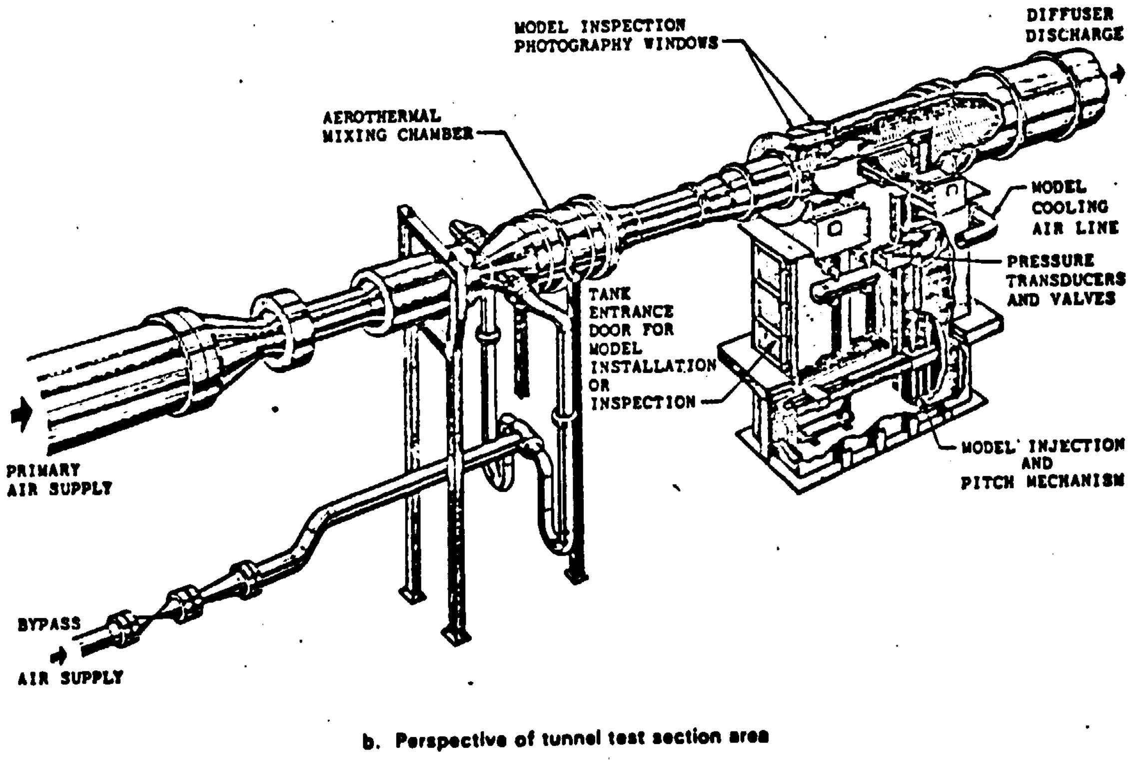
APPENDIX I

ILLUSTRATIONS

ORIGINAL PAGE IS
OF POOR QUALITY



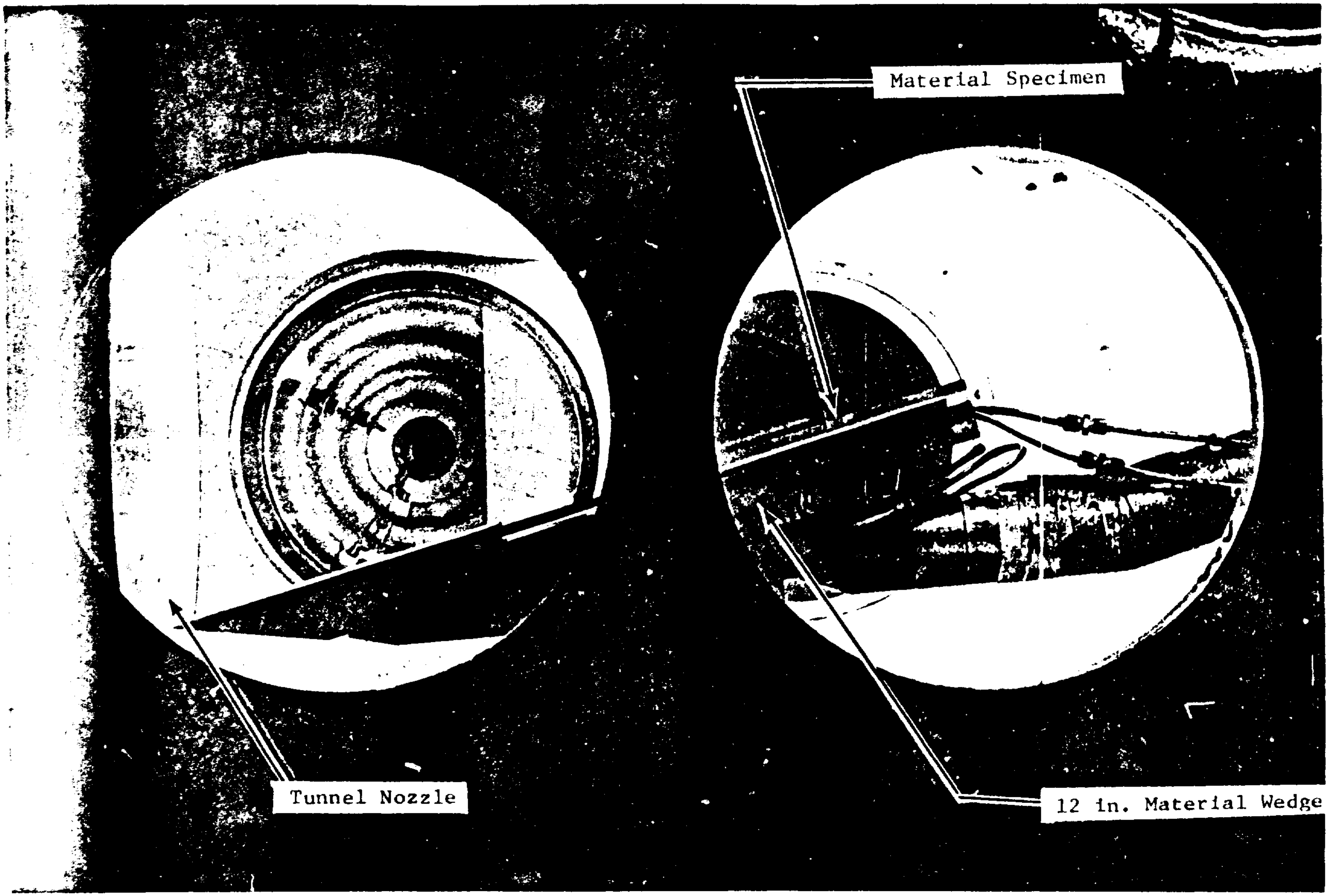
a. Tunnel assembly



b. Perspective of tunnel test section area

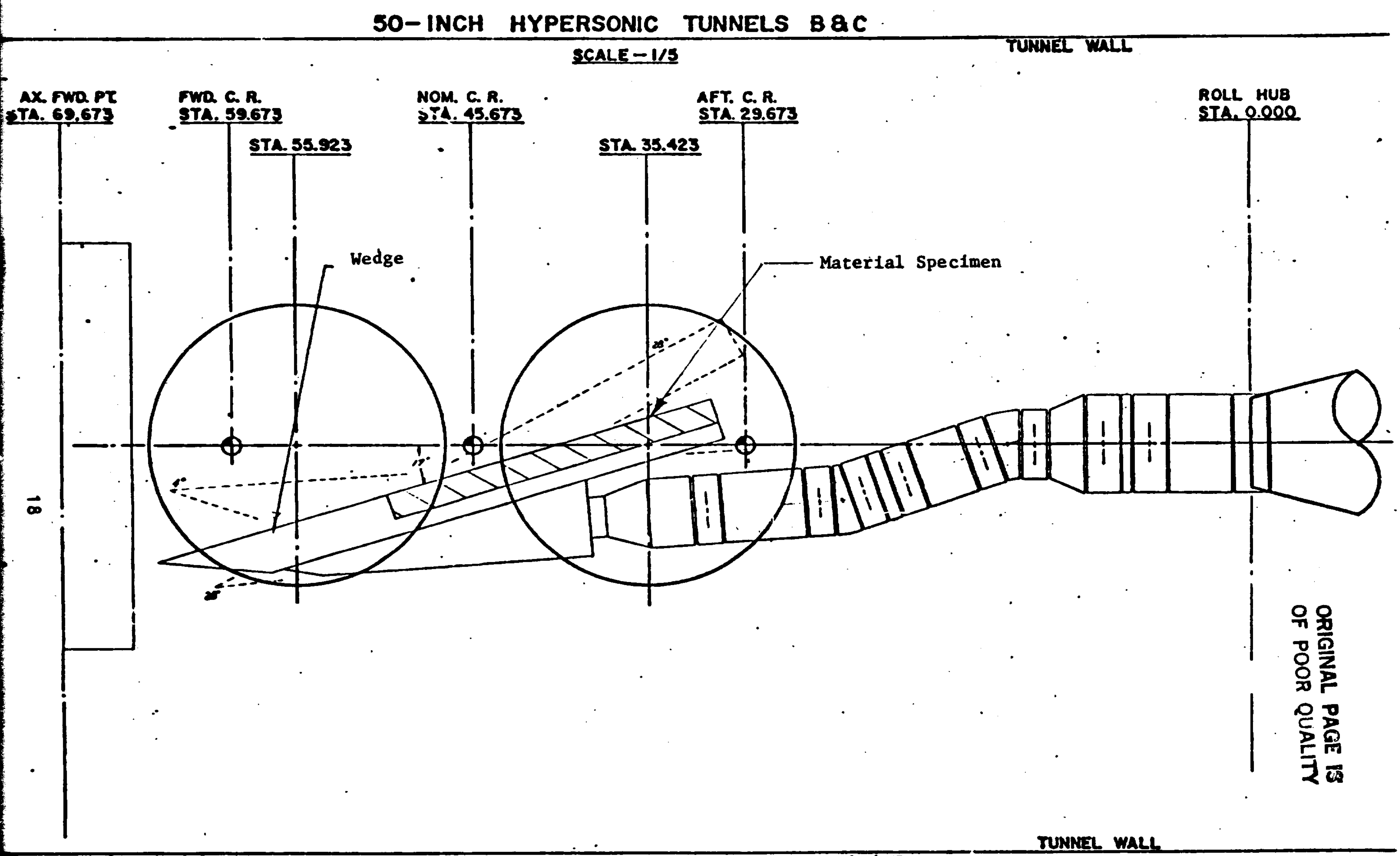
Fig. 1 Tunnel C Mach 4.0 Configuration

ORIGINAL PAGE IS
OF POOR QUALITY



a. Installation Photograph

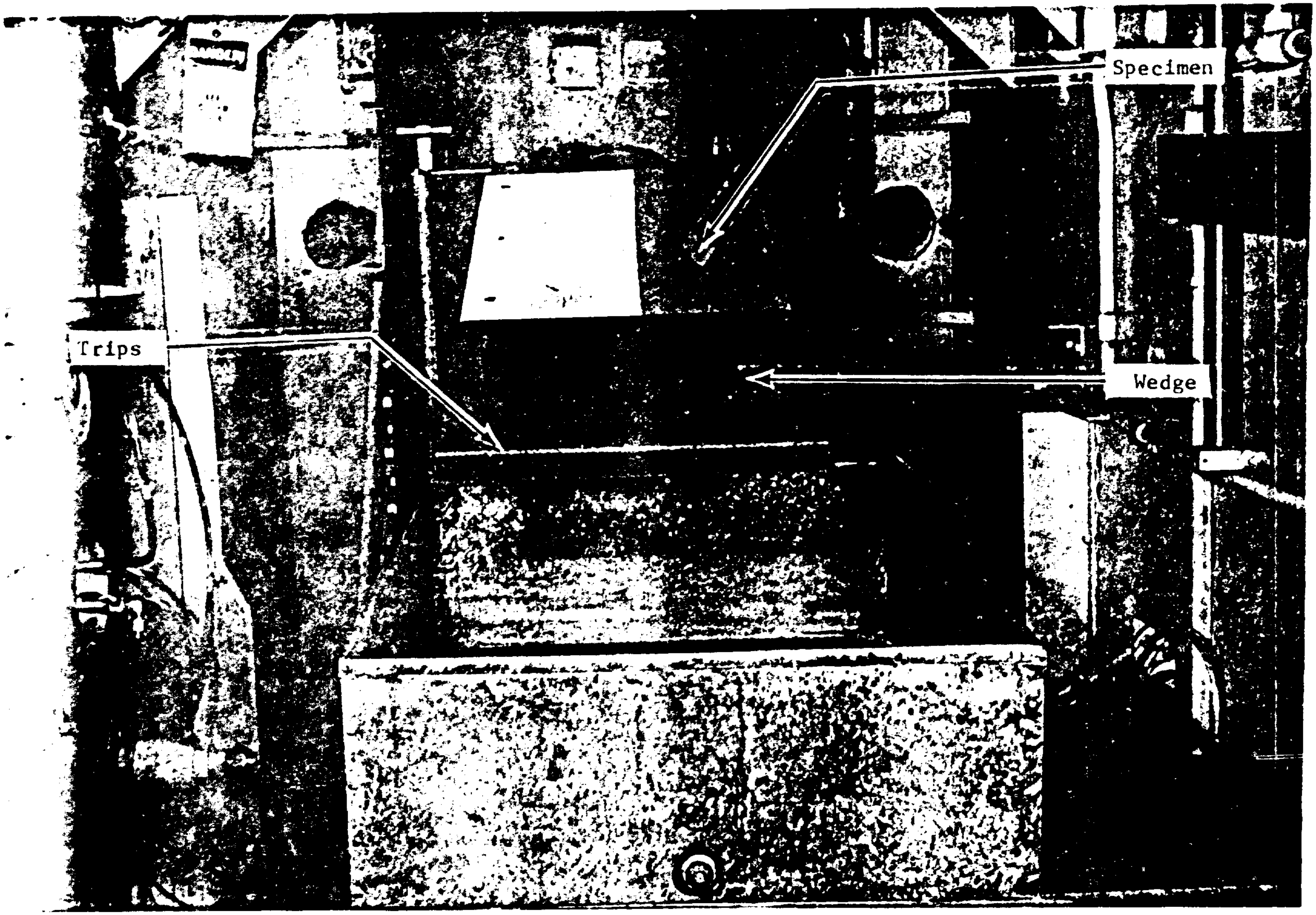
Figure 2. Installation in Tunnel C



b. Installation Sketch for Mach 4 Entry

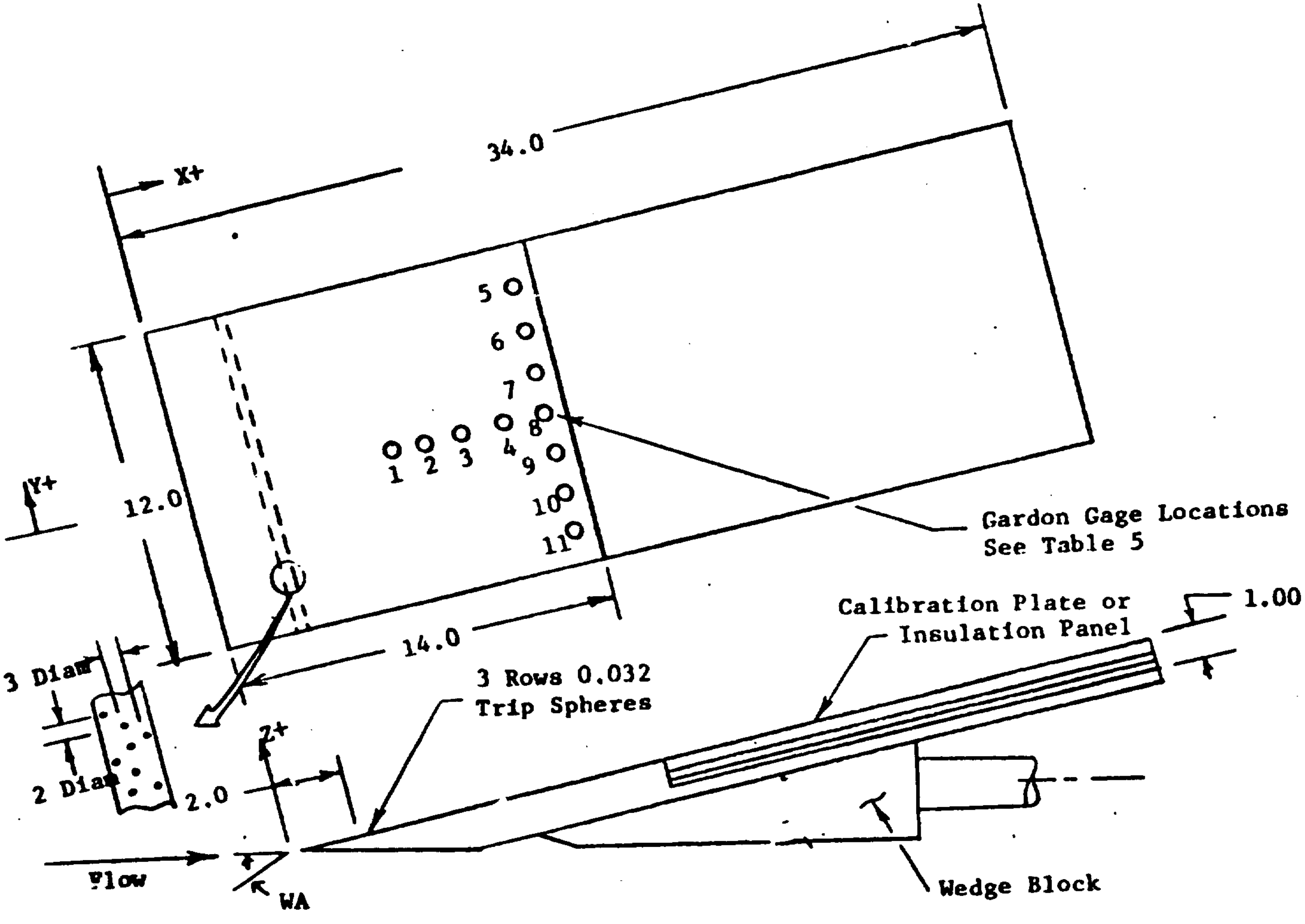
Figure 2. Concluded

ORIGINAL PAGE IS
OF POOR QUALITY



a. Photograph in Tank

Figure 3. Test Article Details



All dimensions in inches
Not to scale

b. Sketch of 12 in. Wide Materials Testing Wedge

Figure 3. Concluded

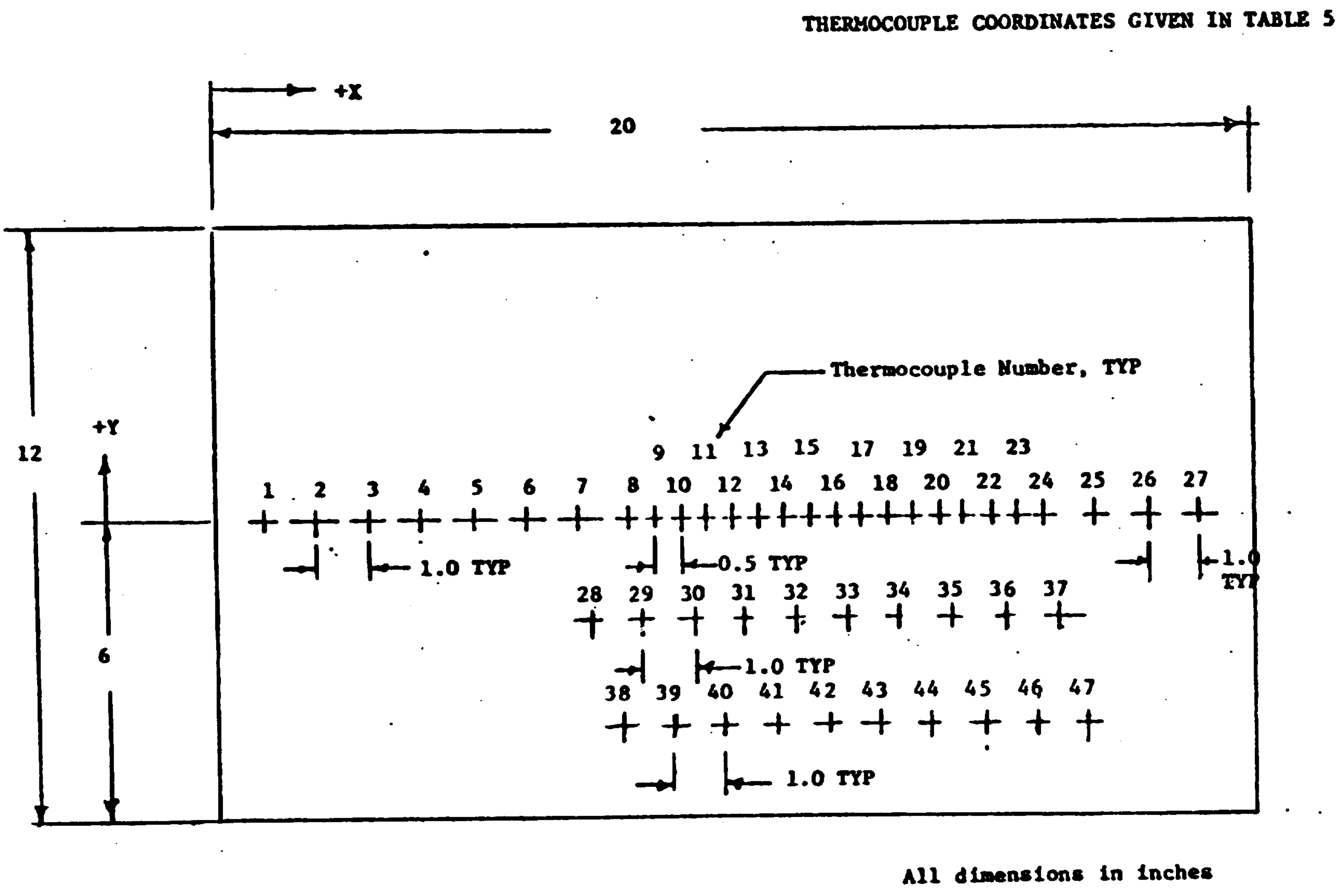
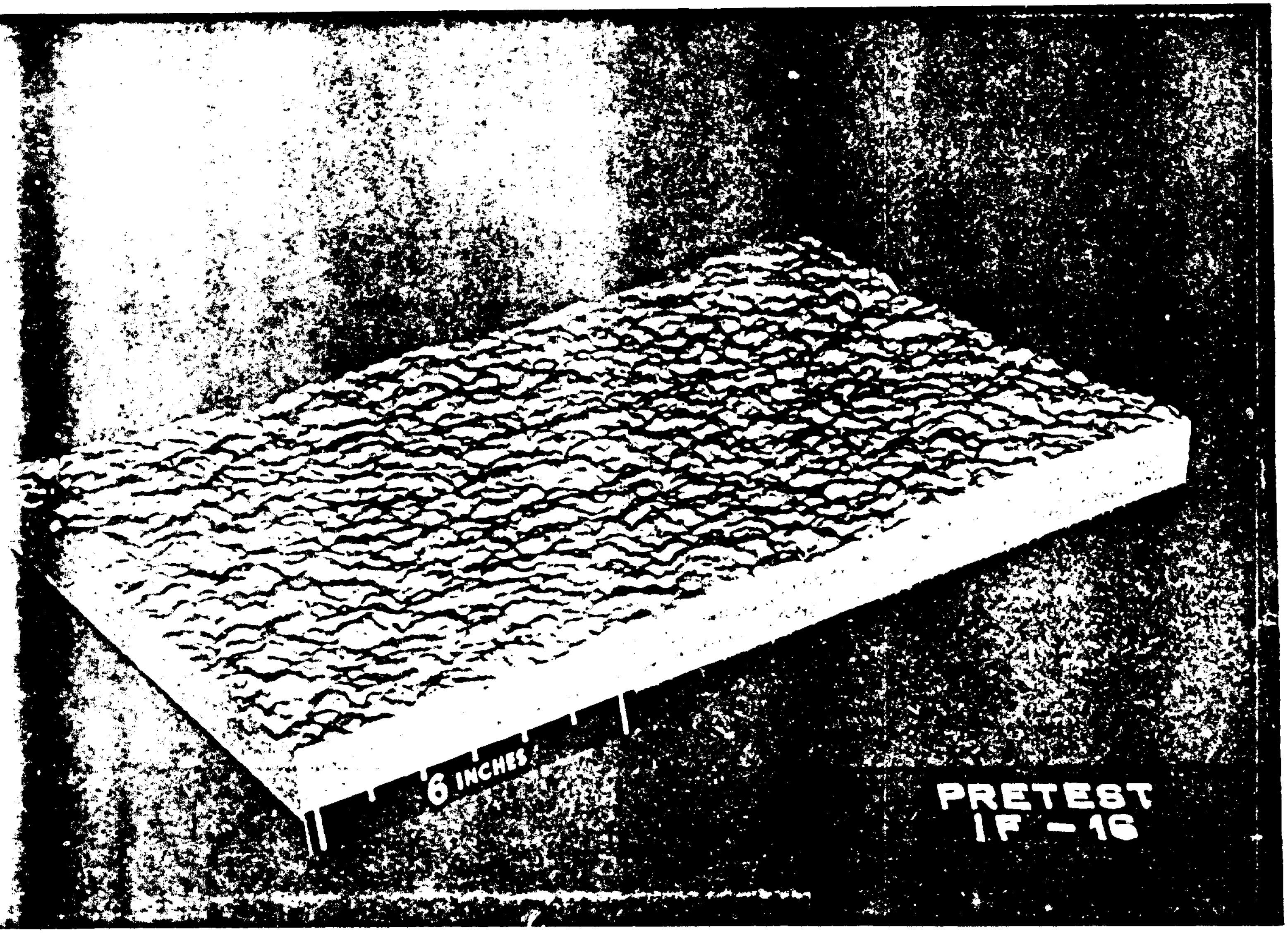


Figure 4. Calibration Plate

ORIGINAL PAGE IS
OF POOR QUALITY

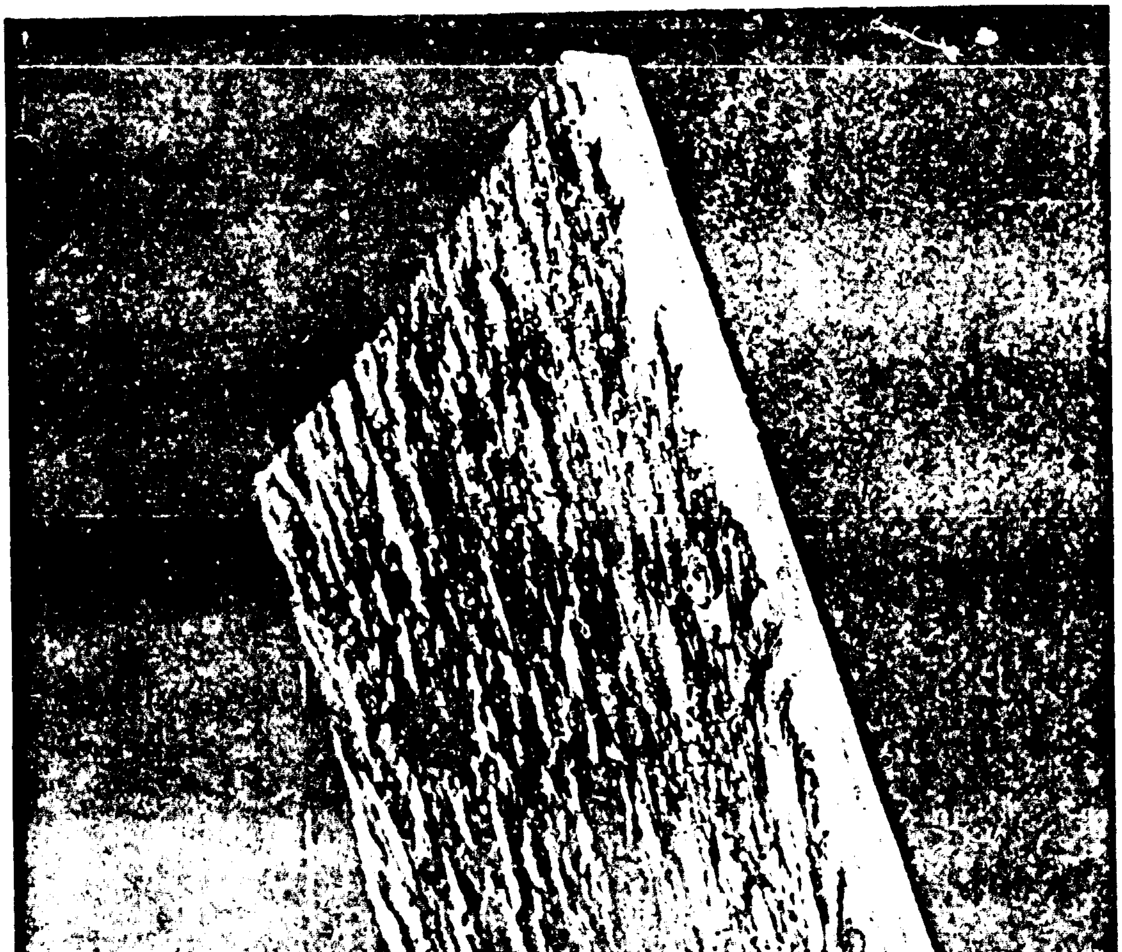
ORIGINAL PAGE IS
OF POOR QUALITY



a. Instafoam Specimen Pretest

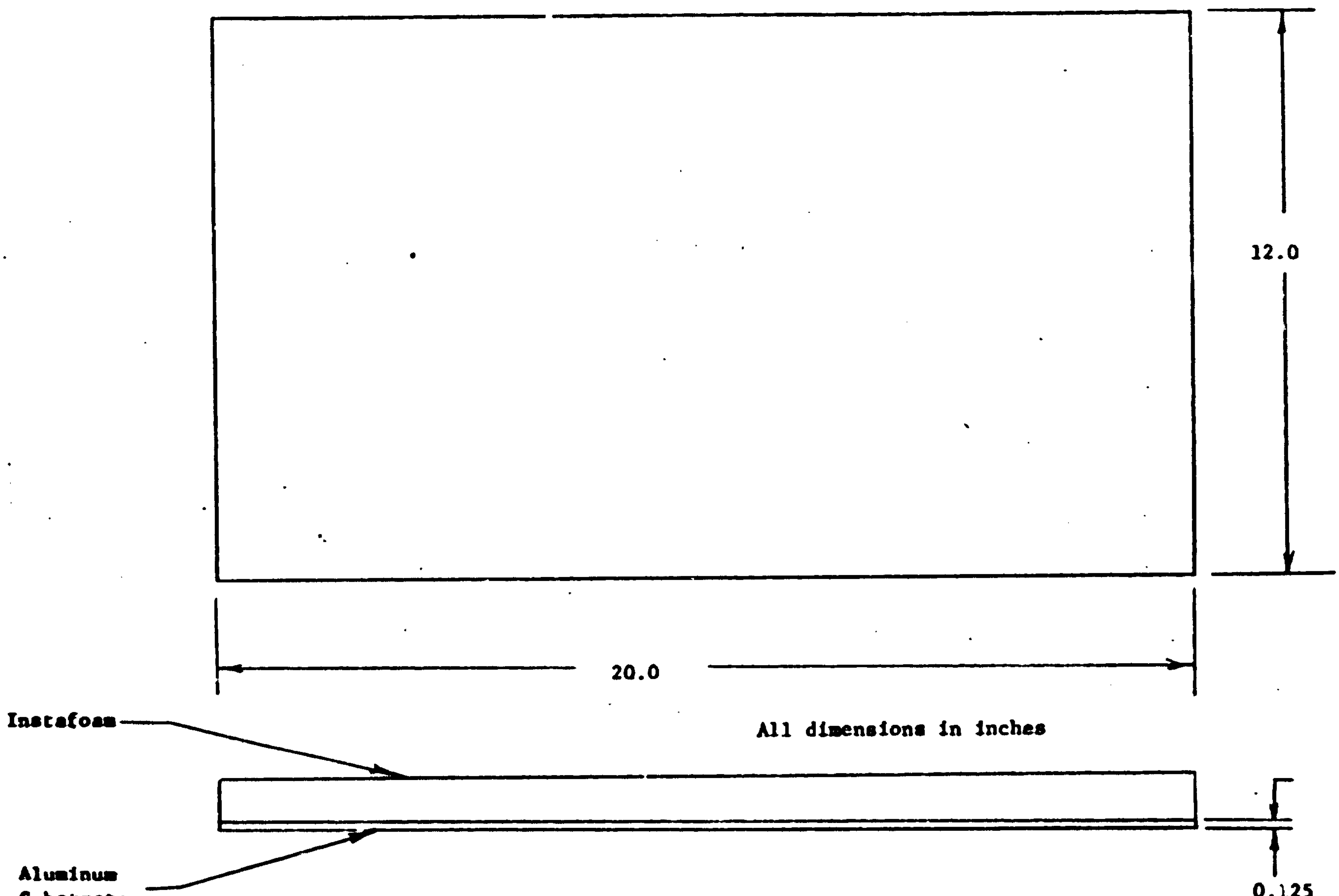
Figure 5. Specimen Configuration

ORIGINAL PAGE IS OF POOR QUALITY



b. Instafoam Specimen Posttest

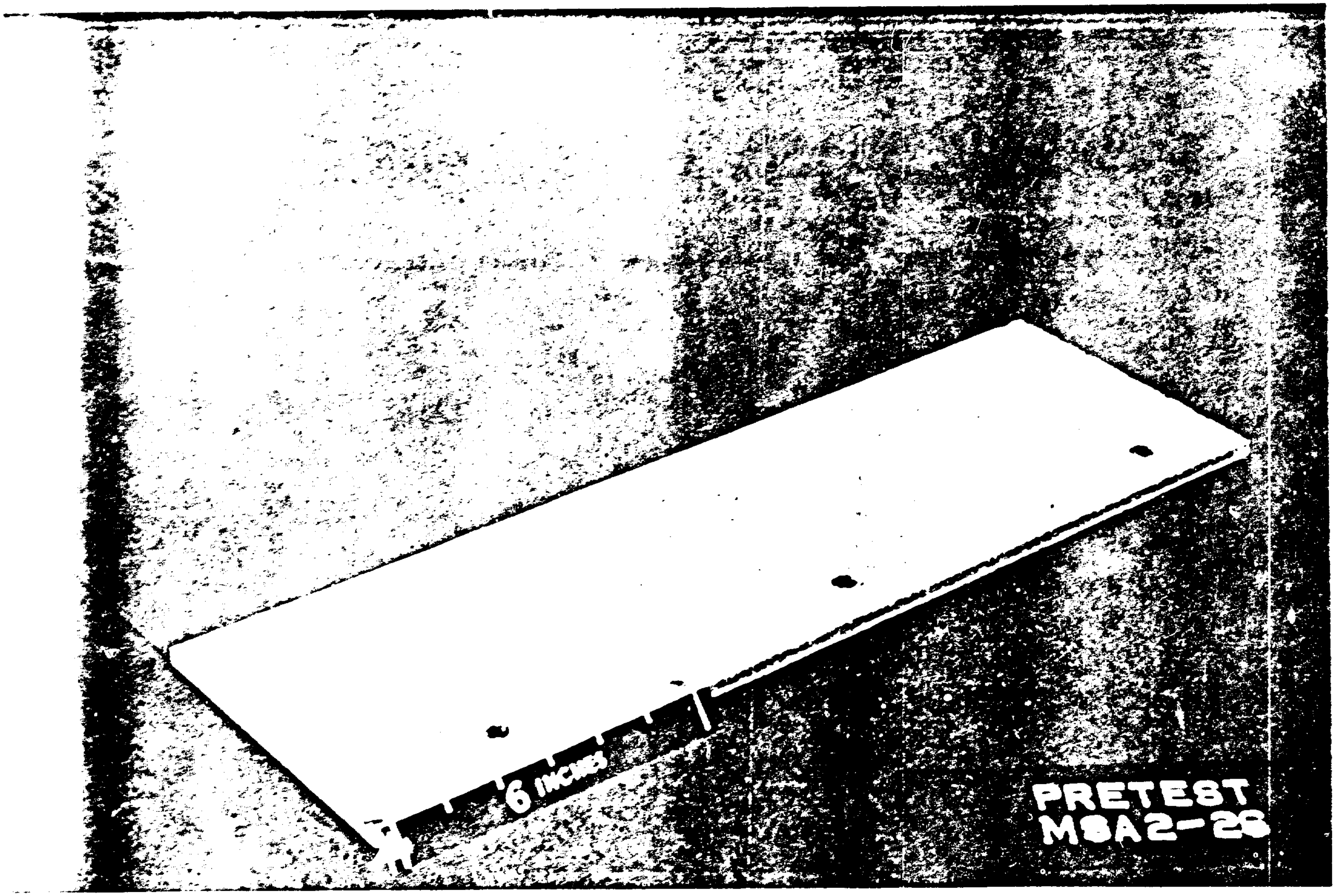
Figure 5. Continued



c. Sketch Instafoam Specimen

Figure 5. Continued

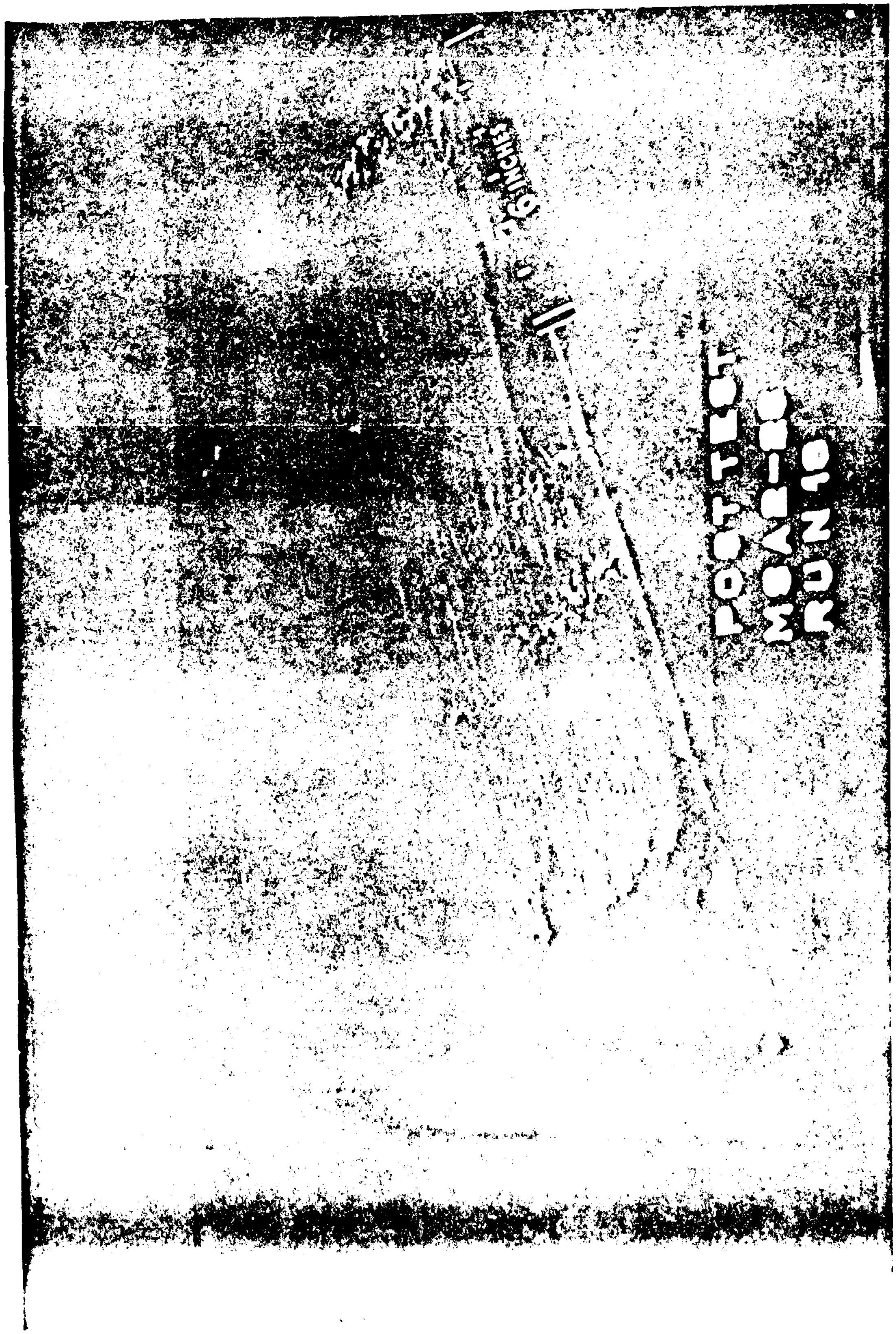
ORIGINAL PAGE IS
OF POOR QUALITY



d. MSA2 Specimen Pretest

Figure 5. Continued

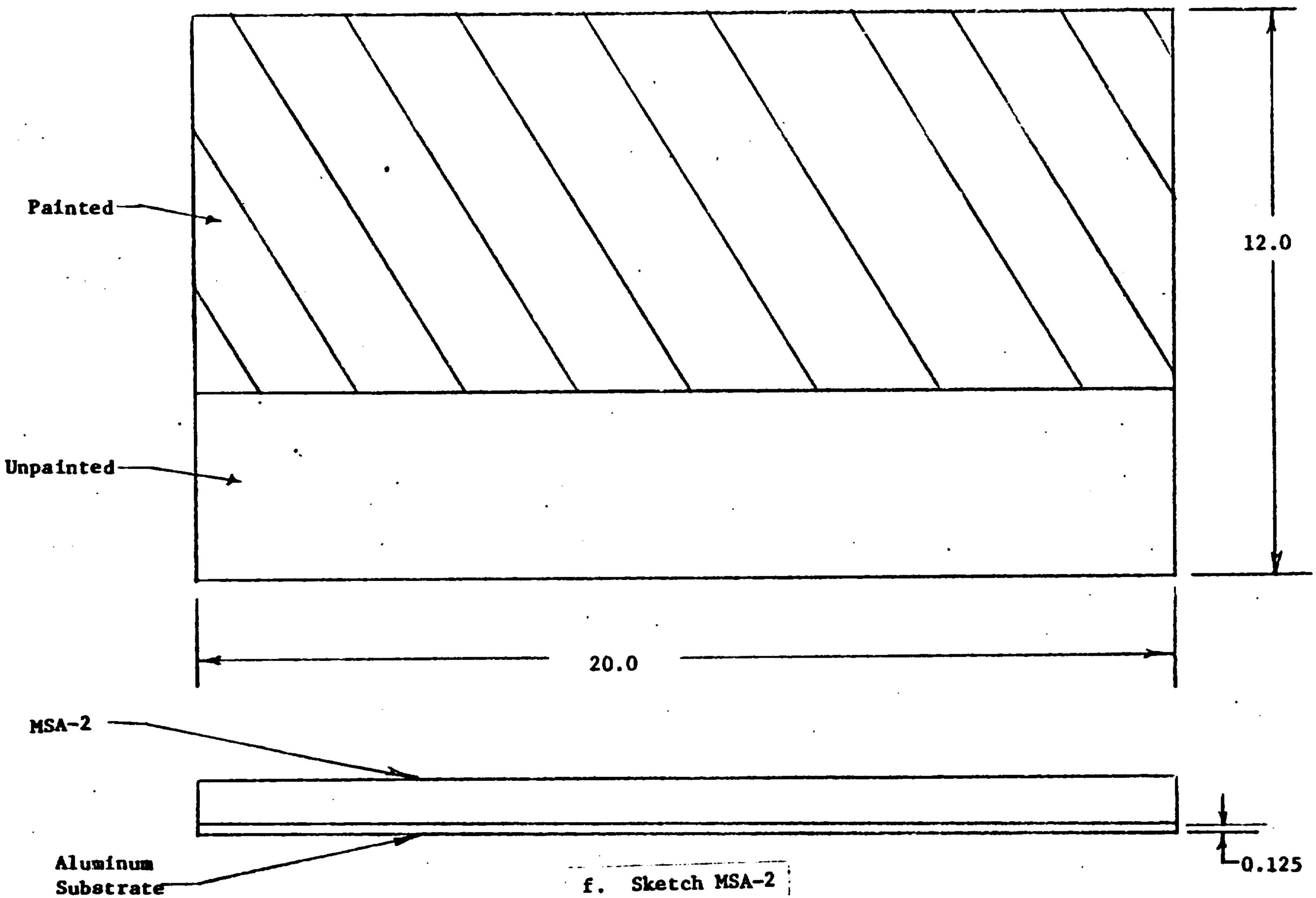
ORIGINAL PAGE IS
OF POOR QUALITY



e. MSA2 Specimen Posttest

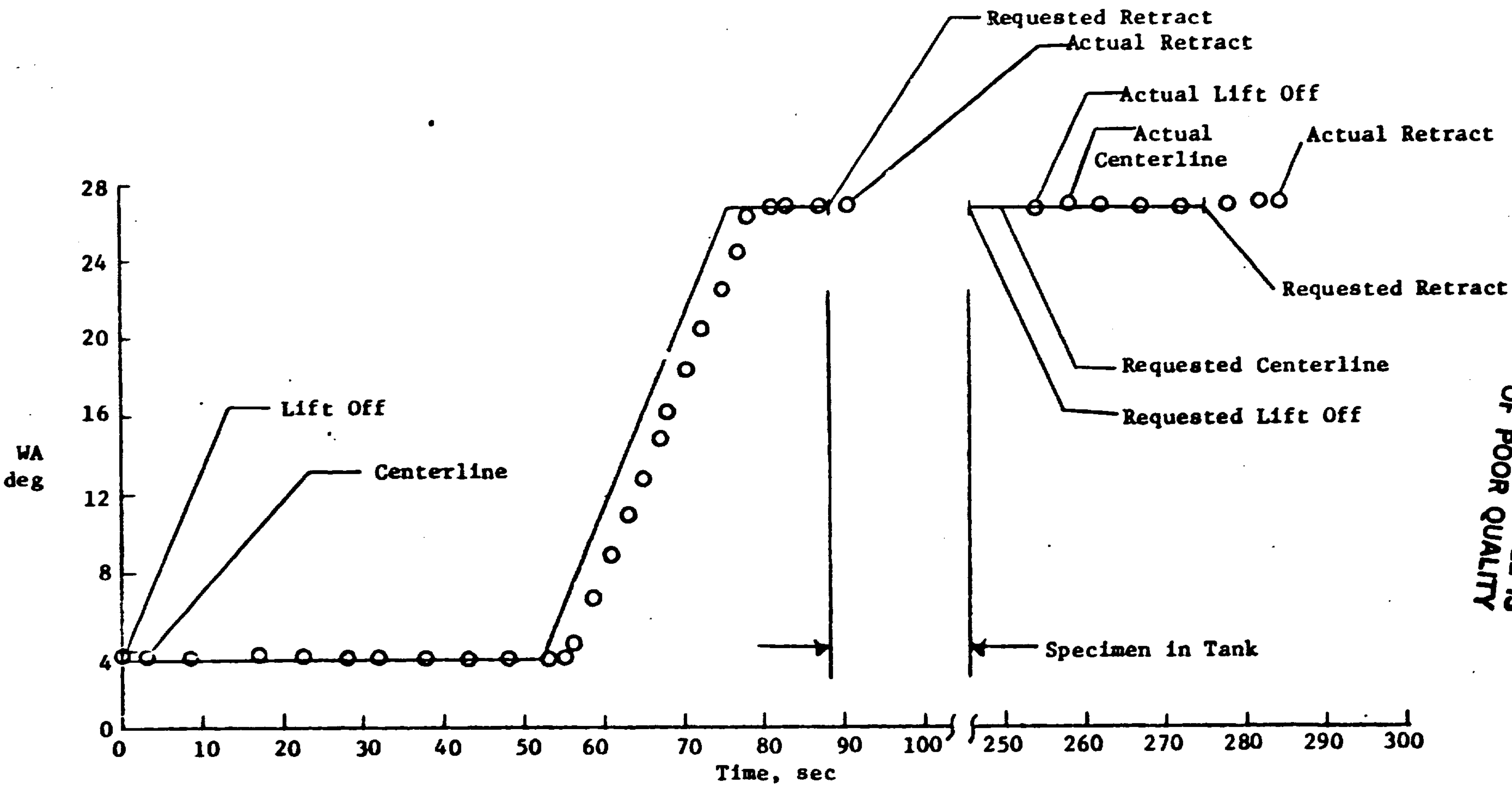
Figure 5. Continued

ORIGINAL PAGE IS
OF POOR QUALITY



f. Sketch MSA-2

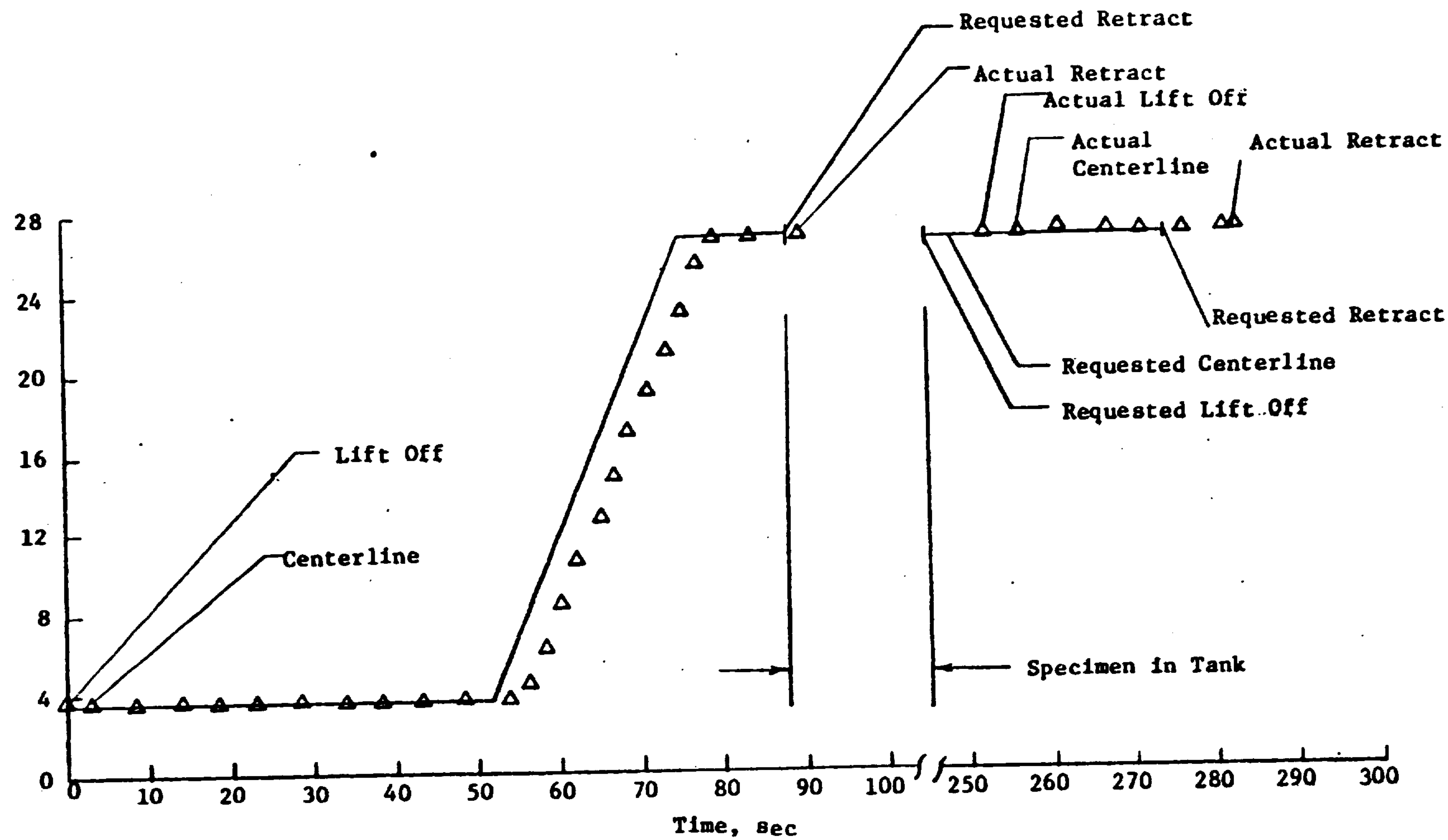
Figure 5. Concluded



a. Run 50

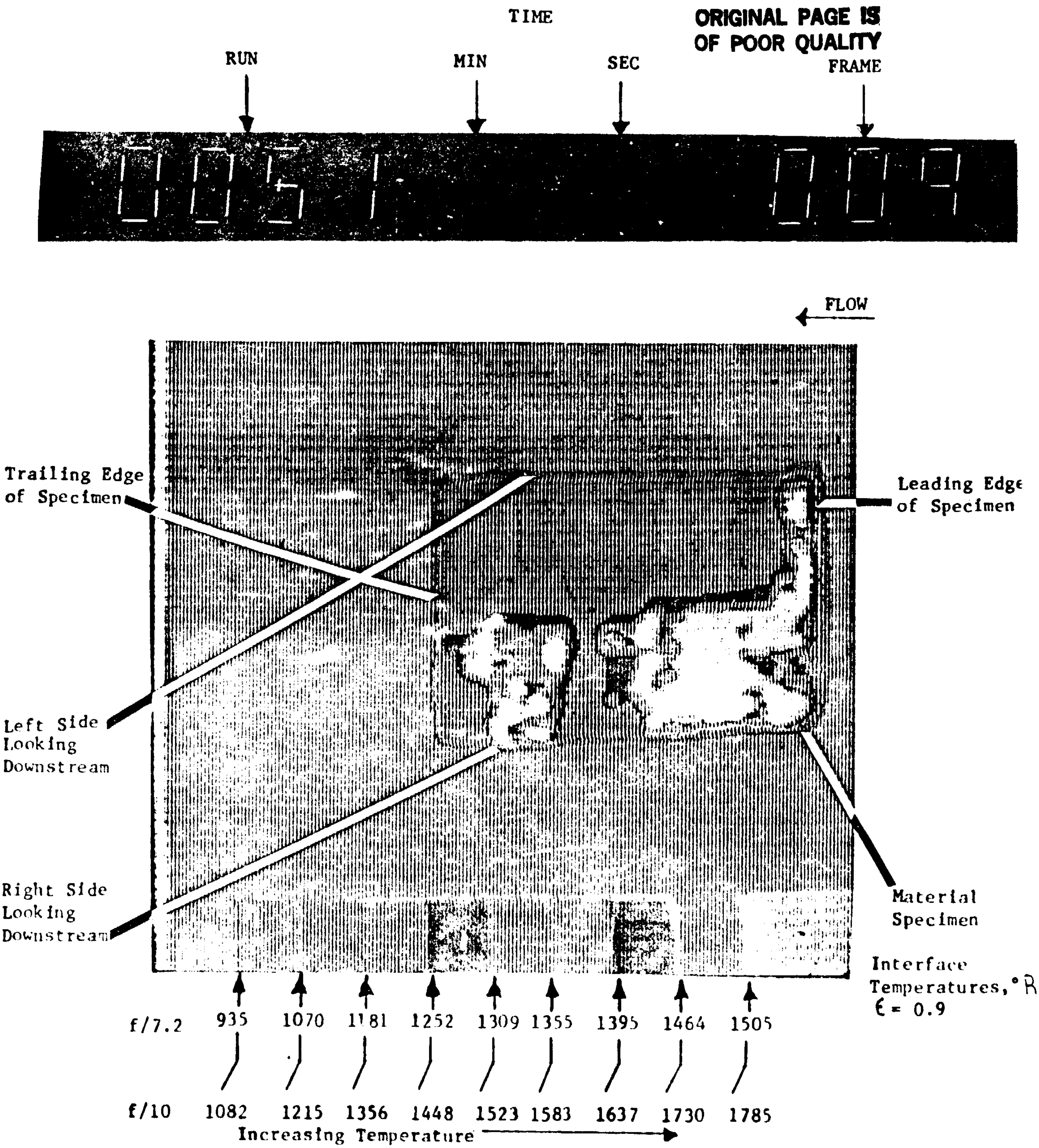
Figure 6. Wedge Trajectory

ORIGINAL PAGE IS OF POOR QUALITY



b. Run 51

Figure 6. Concluded



WA	4	17	28
Leading Edge	Point 101	Point 99	Point 104
Trailing Edge	Point 37	Point 43	Point 41
Right Side Looking Downstream	Line 87	Line 87	Line 87
Left Side Looking Downstream	Line 60	Line 60	Line 60

Figure 7. IR Line Point Identification

ORIGINAL PAGE IS
OF POOR QUALITY

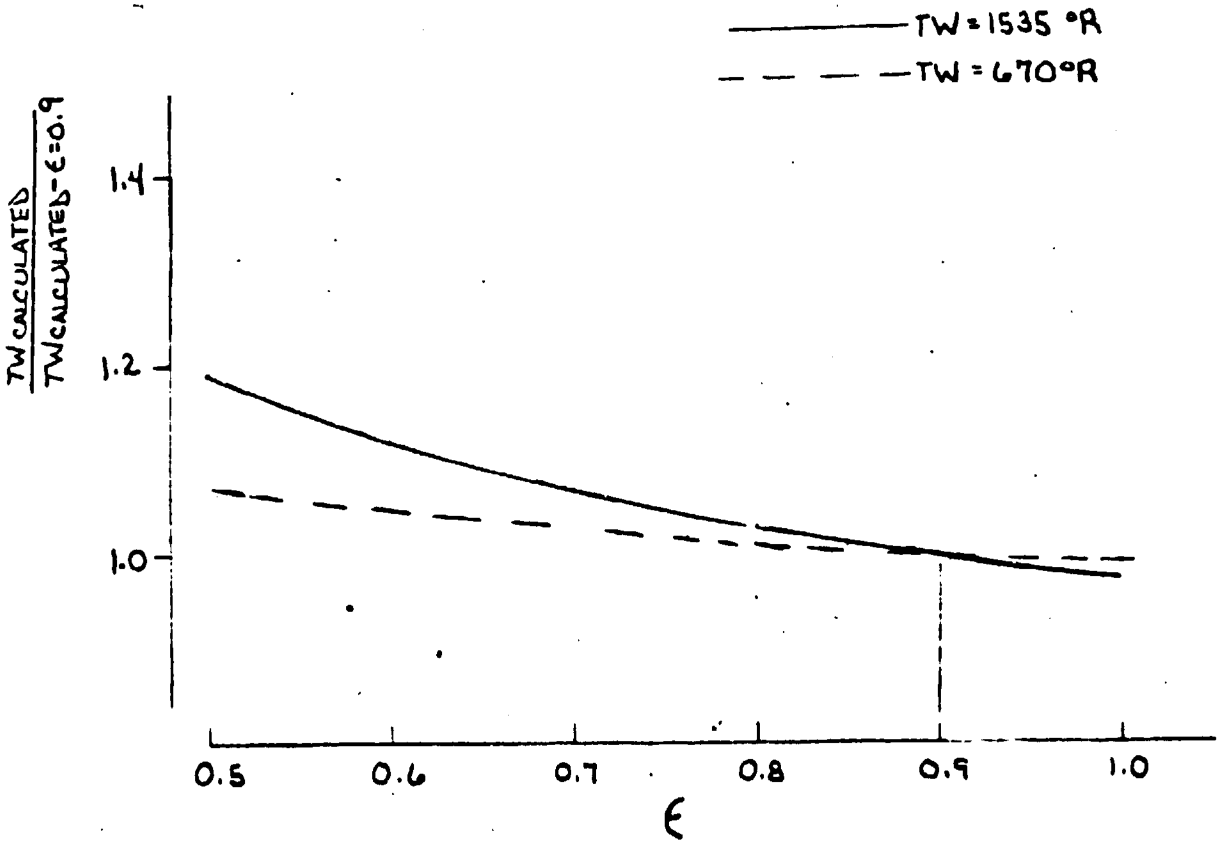


Figure 8. Emissivity-Temperature Sensitivity Curve

ORIGINAL PAGE IS
OF POOR QUALITY

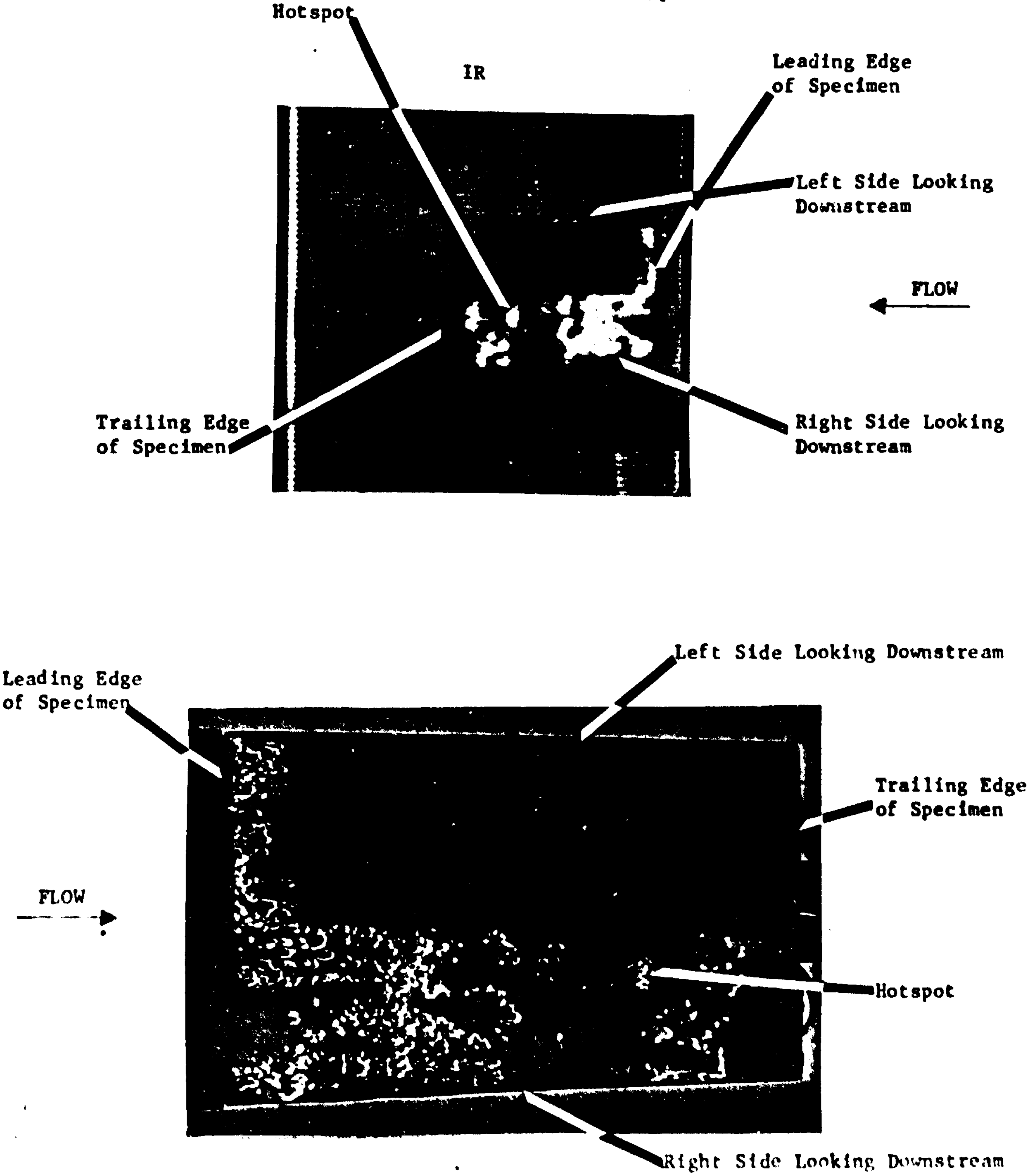


Figure 9. IR-Top Photograph Comparison

241

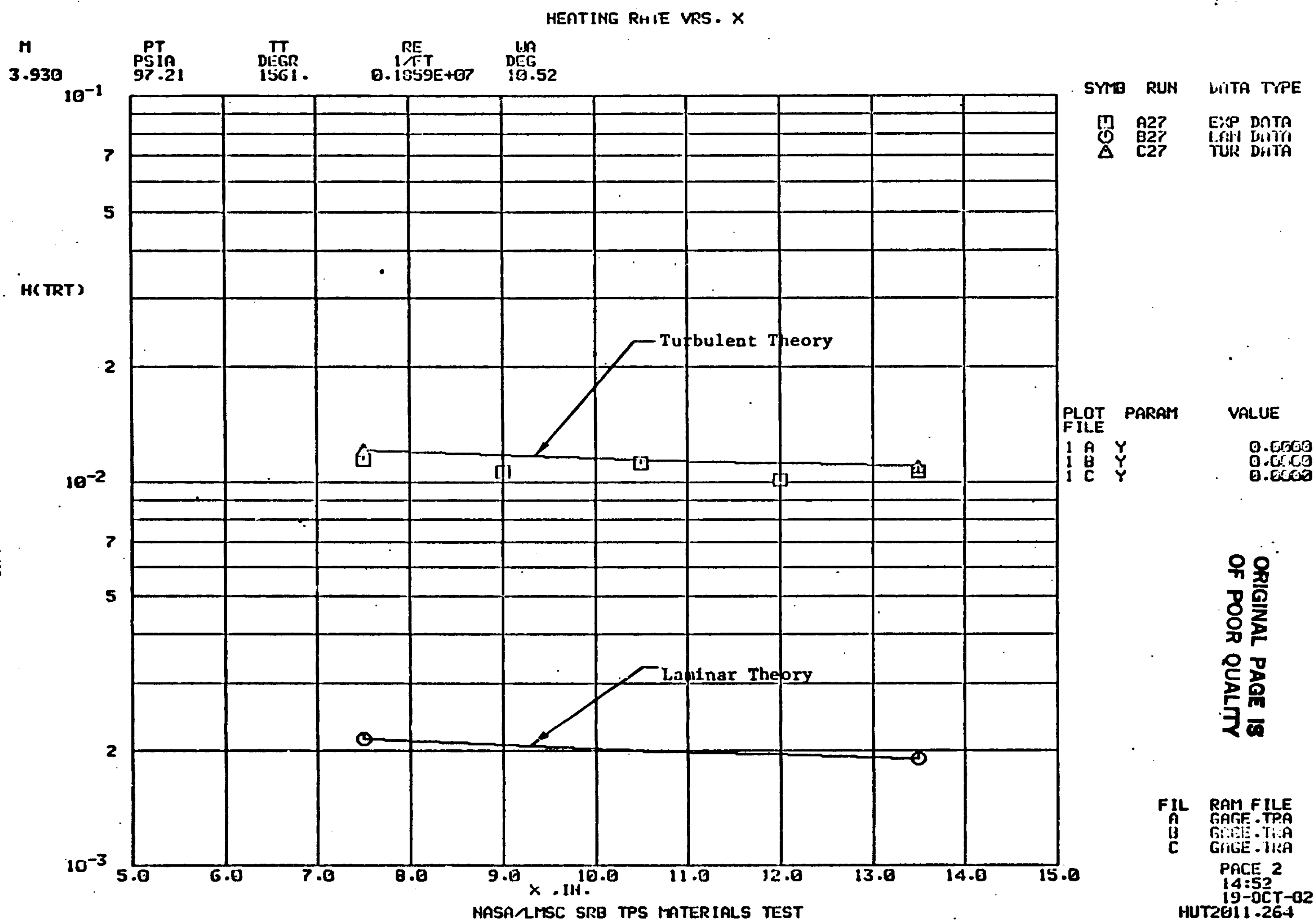


Figure 10. Comparison of Tunnel Data with Analytical Calculation

ORIGINAL PAGE IS
OF POOR QUALITY

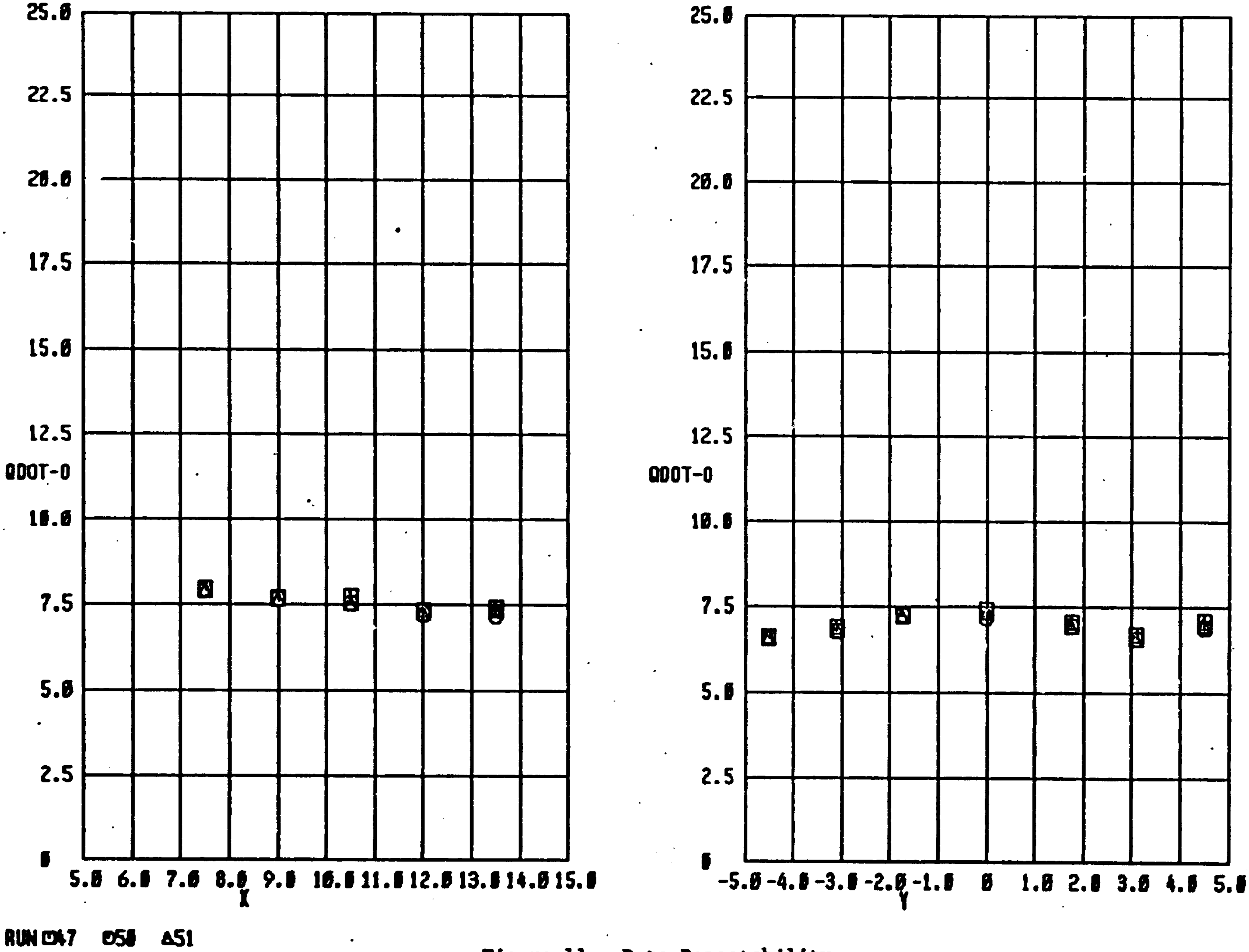


Figure 11. Data Repeatability

APPENDIX II

TABLES

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 1. Data Transmittal Summary

The following items were transmitted to the User and Sponsor

	User	Sponsor
	W. G. Dean Lockheed Missile and Space Co. 4800 Bradford Dr. Huntsville, AL 35812	W. B. Baker NASA/MSFC Huntsville, AL 35812
Item	**No. of Copies**	**No. of Copies**
Final Data Package Vols. 1 and 2 of 2	3	3
Installation Photos	1 each 8x10 prints	1 each 8x10 prints
Specimen Pretest Photos	1 each 8x10 prints	1 each 8x10 prints
Specimen Posttest Photos	1 each 8x10 prints	1 each 8x10 prints
70 mm Sequence Tunnel & IR	1 contact print 1 duplicate negative	1 contact print
16 mm Direct Movies Tunnel & IR	1 work print optical master	1 work print

TABLE 2. Material Summary

Sample Number	Run Number	Sample Material	Thickness (inches)
IF-01	69	Instafoam	1.0
-02	23		
-03	68		
-04	22		
-05	14		
-06	13		
-07	47		
-08	46		
-09	45		
-10	44		
-11	49		
-12	48		
-13	43		
-14	27		
-15	42		
-16	41		
-17	40		
-18	26		
MSA2-01	17	MSA2	0.5
-02	52		
-03	31		
-05	63		*
-07	10,11		0.5
-08	61		
-09	29		
-11	8		
-12	59		
-13	30		
-15	9		
-16	60		
-17	28		
-19	62		*
-20	56		0.25
-21	36		
-22	20		
-23	55		
-25	25		
-26	18		
-27	35		
-28	19		
-29	54		
-31	37		0.5
-32	64		
-33	16		
-34	33		
-36	67		0.25
-38	66		
-39	38		
-40	65		
-42	21		0.5
-43	34		

* Thickness not measured

TABLE 2. Concluded

Sample Number	Run Number	Sample Material	Thickness (inches)
MSA2-44	15	MSA2	0.5
-46	24		
-47	58		
-48	12		
-51	53		0.25
-52	50		0.50
-54	57		
-55	51		

TABLE 3. ESTIMATED UNCERTAINTIES

a. Basic Measurements

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT[a]							Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Precision Index (S)			Bias (B)		Uncertainty ±(B + t_{95}S)					
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement				
STILLING CHAMBER, PRESSURE, PT, psia		0.18	>30		0.78		0.485	<156	Wiancko variable reluctance pressure transducer	Digital data acquisition system analog-to-digital converter	In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the standards laboratory
TOTAL TEMPERATURE, TT, °F		1 1	>30 >30	0.375	2		4 ±(.375% +2°F)	32 to 530 530 to 2300	Chromel®-Alumel® thermocouple	Doric temperature instrument digital multiplexer	Thermocouple verification of NBS conformity/voltage substitution calibration
PITCH ANGLE, ALPHI, deg		0.025	>30				0.05	15	Potentiometer		Heidenhain rotary encoder ROD700 Resolution: 0.0006° Overall accuracy: 0.001°
TIME		$5x10^{-4}$	>30	Runtime(sec)x5x 10^{-6}		Runtime(sec)x5x 10^{-6})+10^{-3}		ms to 365 days	Systron Donner time code generator	Digital data acquisition system	Instrument lab calibration against Bureau of Standards
HEAT TRANSFER, QDOT, BTU/ft²-sec	1.5	0.015	>30 >30	2 2		(0.03 + 2%) 5%		<1 1 to 10	Gardon gage	Digital data acquisition system analog-to-digital converter	Radiant heat source and secondary standard
E_{mv}	0.1		>30	0.01		(0.2% + 0.01)			DEC-10/Multiverter Preston amplifier		Millivolt standard, referenced to lab standard
TEMPERATURE, TGE, °F		1 1	>30 >30	3/8%	2	4 (3/8% + 2°F)		32 to 530 530 to 2300	CrAl thermocouple		
IR Spot Temperature, θ_R	0.5		>30	0.2		1.2%			AGA 680 Thermovision	Analog-to-Digital Converter	Secondary Standard Black Body Temperature Source

[a] Thompson, J. W. and Abernethy, R. B. et al. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356) February 1973.

GC-180 (2/81)

ORIGINAL PAGE IS OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 3. Concluded

b. Calculated Parameters

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT*							Range
	Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{95}S)$		
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement	
H(TT), BTU/ft^2-sec-^oR GARDON GAGE	2.0		>30	2.0		6.0		
M	0.38		>30			0.76		3.9-4.0
QDOT-0, BTU/ft^2-sec GARDON GAGE	2.0		>30	2.0		6.0		
TW, ^oR		1	>30		2	4		All
WA, deg		0.05	>30		0+		0.10	All
RE ft^{-1}	0.70		>30	0.56		1.96		$0.5 \times 10^6 ft^{-1}$
	0.36		>30	0.45		1.17		$3.7 \times 10^6 ft^{-1}$
H(TT), BTU/ft^2-sec-^oR	1.0		>30	6.0		8.0		1×10^{-3}
Thin Skin Thermocouple	4.0		>30	6.0		14.0		1×10^{-4} – 1×10^{-3}
	7.0		>30	6.0		20.0		$< 1 \times 10^{-4}$

*Abernethy, R. B. et al. and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.

+Assumed to be zero

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4. Photographic Data Summary

	Camera Type	Frame Rate	Camera Location	Sample View	Film Roll No.	Run Numbers
Camera 1	Varitron 70 mm still	1 frame/4 sec	Top upstream window	Top of specimen on centerline	426,428 311,313 315,317 345,347	8-21,22-27 28-30,31-37 38-51,52-58 59-67,68-72
Camera 2	DBM-55 16 mm movie	24 fps	Top upstream window	Top of specimen on centerline	4782,4784,4786 4351,4353,4355 4357,4359,4361 4369,4372,4374 4376,4378	8-15,16-20,21-27, 28-30,31-33,35,36, 37&38,39-47,48-52, 53&54,55-57,58-61 62-65,66-72
Camera 3	Varitron 70 mm still	1 frame/4sec	Operating side upstream window	Left side view of forward position of specimen on centerline	427,429 312,314 316,318 346,348	8-21,22-27 28-30,31-37 38-51,52-58 59-67,68-72
Camera 4	DBM-55 16 mm movie	24 fps	Operating side upstream window	"	4783,4785,4787 4352,4354,4356 4358,4360,4368 4370,4373,4375 4377,4379	8-15,16-20,21-27 28-30,31-33,34-36 37&38,39-47,48-52 53&54,55-57,58-61 62-65,66-72
Camera 5	Varitron 70 mm still shadowgraph stills	1/min	Operating side downstream window	Downstream window	425,297,306	4-27,28-30,31-72
Camera 5A	Varitron 70 mm shadowgraph stills	1/min	Operating side upstream window	Upstream window	430	4-7
Camera 6	BOLEX, IR movies	8 fps	IR room	IR screen	*4788,4380, 4381,4382,4383 4386,4387	8-27,28-37 38-54,55-67,68-72 1-25,26,62
Camera 7	Hasselblad IR stills	1 frame/10 sec	IR room	IR screen	*1,2,3 1a,2a	8-10,13-21,22-27 28-72,8-62

* IR movies rolls 4386 & 4387 and Hasselblad roll 2a were taken from mag tape

TABLE 5. Instrumentation Locations

a. Gardon Gages

Gardon Gage No.	X, in.	Y, in.
1	7.5	0
2	9.0	0
3	10.5	0
4	12.0	0
5	13.5	4.5
6	13.5	3.1
7	13.5	1.75
8	13.5	0
9	13.5	-1.75
10	13.5	-3.1
11	13.5	-4.5

TABLE 5. Concluded

b. Flat Plate Calibration Model Thermocouple

T/C No.	X, in.	Y, in.	Skin Thickness, in.
1	15	0	0.062
2	16		
3	17		
4	18		
5	19		
6	20		
7	21		
8	22		
9	22.5		
10	23.0		
11	23.5		
12	24		
13	24.5		
14	25		
15	25.5		
16	26		
17	26.5		
18	27		
19	27.5		
20	28		
21	28.5		
22	29		
23	29.5		
24	30		
25	31		
26	32		
27	33		
28	21.2	-2	
29	22.2		
30	23.2		
31	24.2		
32	25.2		
33	26.2		
34	27.2		
35	28.2		
36	29.2		
37	30.2		
38	21.7	-4.2	0.063
39	22.7		
40	23.7		
41	24.7		
42	25.7		
43	26.7		
44	27.2		
45	28.7		
46	29.7		
47	30.7		

TABLE 6.

Run Summary

ORIGINAL PAGE IS OF POOR QUALITY

RUN	SAMPLE NUMBER	PT psia	TT °R	WA, deg	IR f-stop	IR rate sec/frame	TIME expt sec	REMARKS
1	-	30	690	17.0	-	-	5	Blockage runs
2	-		765	23.1	-	-	5	
3	-		800	28.1	-	-	4	
4	-	100	1860	17.1	-	-	4	
5	-		1900	21.2	-	-	9	
6	-			25.3	-	-	10	
7	-			28.3	-	-	5	
8	MSA2-11			17.2	7.2	6	109	IR data mag tape
9	MSA2-15			23.0			81	No data acquired TIMEEXPT and WA interred by Test log
10	MSA2-07			19.8			109	No IR data, sample injected twice due to failure to fully retract sample
11	MSA2-07			19.6			21	
12	MSA2-48			19.8		4	53	IR data mag tape
13	IF-06			27.1		4	26	
14	IF-05			19.8		4	17	
15	MSA2-44			27.1		6	107	
16	-33			19.8	10	5	82	
17	-01			27.1		4	68	
18	-26			13.6		5	74	
19	-28			10.1		4	70	
20	-22			6.6		9	154	
21	-42			16.3		9	145	
22	IF-04			13.6		10	17	
23	IF-02			6.6		2	17	
24	MSA2-46		1560	28.4		15	65	
25	MSA2-25			10.5		15	182	
26	IF-18			28.4		2	17	
27	IF-14			10.5		2	22	
28	MSA2-17			28.4		10	123	
29	MSA2-09			23.1			131	
30	-13			18.8			159	
31	-03			18.7			163	
32	-45			28.4			176	
33	-34			23.1		11	180	IR data mag tape
34	-43			18.8		10	178	
35	-27			14.7		15	151	
36	-21			6.0		10	165	
37	-31			14.7			294	
38	-39			10.5			191	
39	-37			6.0			197	
40	IF-17			23.2		3	19	
41	IF-16			18.8		3	21	
42	-15			14.7			30	
43	-13			6.0			64	

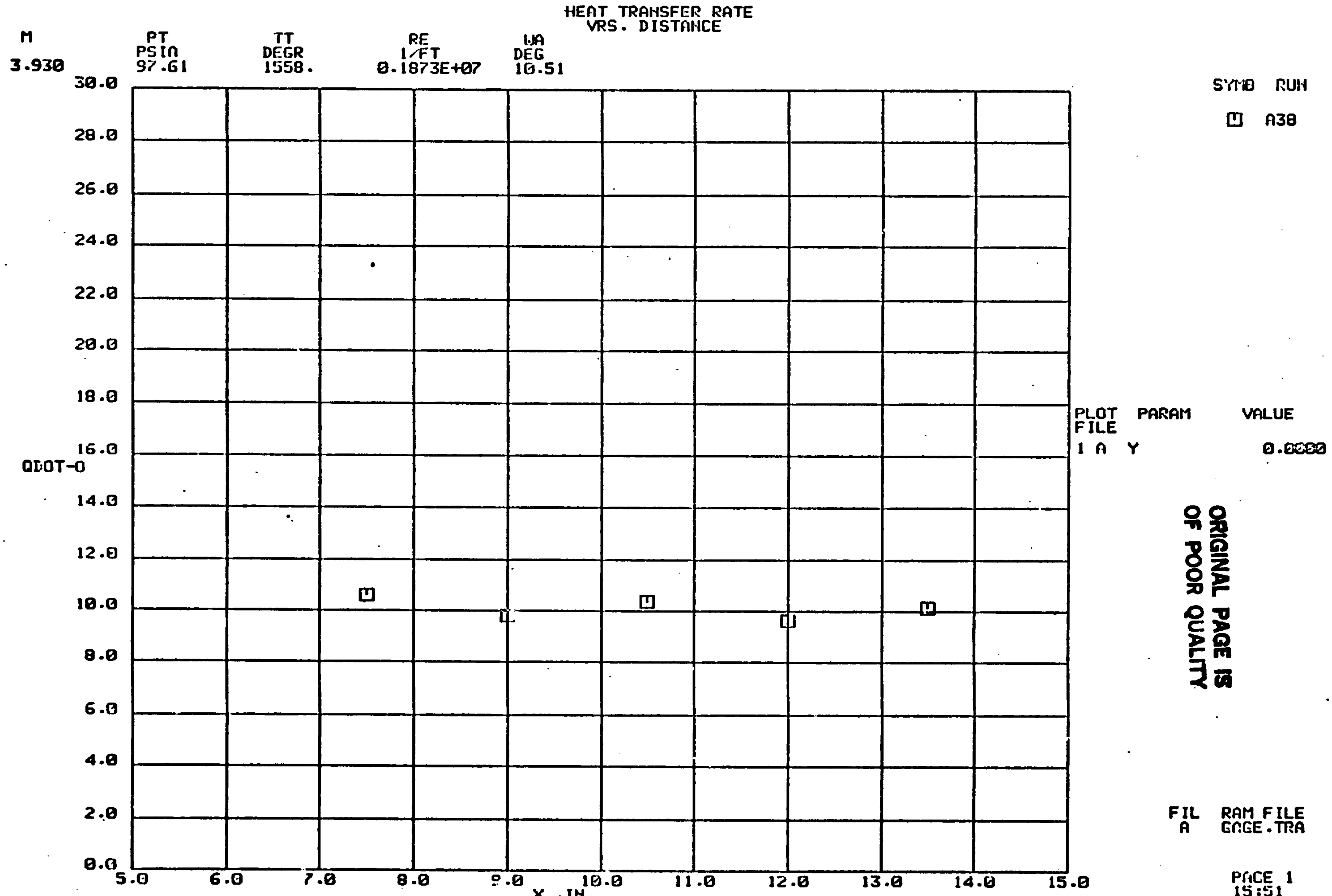
TABLE 6

Concluded

RUN	SAMPLE NUMBER	PT psia	TT °R	WA, deg	IR f-stop	IR rate sec/frame	TIME expt sec	REMARKS
44	IF-10	100	1730	15.3	10.0	3	33	
45	-09			11.6			32	
46	-08			8.0			42	
47	-07			3.8			56	
48	-12			27.0			21	
49	-11			18.8			24	
50	MSA2-52			3.4		10	89	
51	-55			3.7			88	
52	-02			15.3			171	
53	-51			3.7		15	344	
54	-29			11.7		10	146	
55	-23			8.0			165	
56	-20			3.7			198	
57	-54			22.0			133	
58	-47			22.0			104	
59	-12			27.0			100	
60	-16			22.0			127	
61	-08			18.8			127	
62	-19			3.8		11	189	IR data mag tape
63	-05			15.3		10	97	
64	-32		1900	13.6			127	
65	-40			10.1			102	
66	-38			6.6			108	
67	-36			3.2			168	
68	IF-03			10.2		3	23	
69	-01			3.3		3	34	
70	-19		1720	11.7		3	25.7	
71	MSA2-04		1726	15.3		10	87.3	
72	MSA2-14		1560	28.4		10	173	

APPENDIX III

SAMPLE TABULATED AND PLOTTED DATA



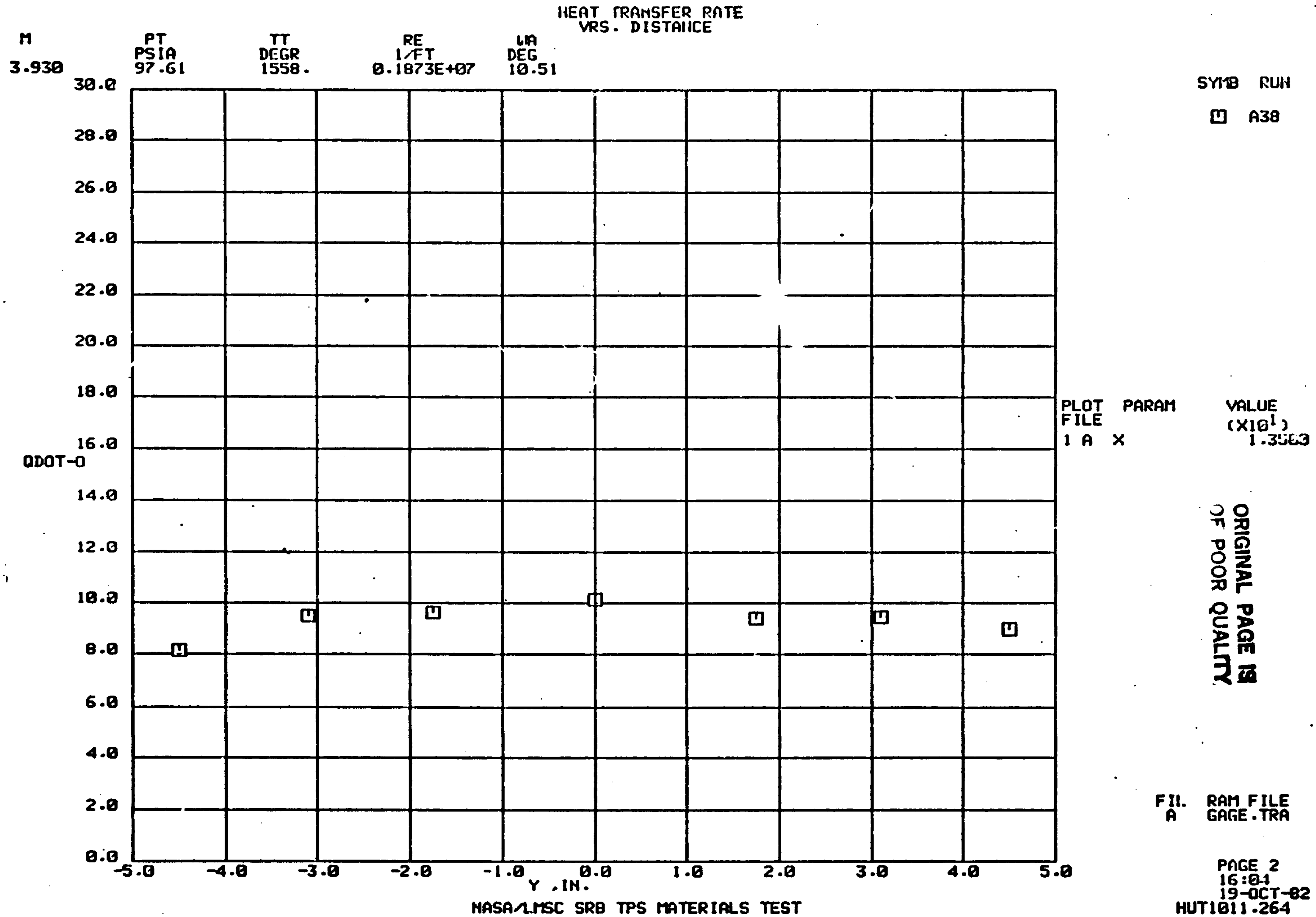
NASA/LMSC SRB TPS MATERIALS TEST

a. Heat Transfer Rate vs X

Sample 1. Heat Transfer Data

ORIGINAL PAGE IS
OF POOR QUALITY

417



b. Heat Transfer Rate vs Y

Sample 1. Continued

ORIGINAL PAGE IS
OF POOR QUALITY

ARVIN/CALSPAN FIELD SERVICES, INC.
AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/LMSC SRM TPS MATERIALS TEST
PAGE 4

DATE COMPUTED 18-OCT-82
TIME COMPUTED 14:32:05
DATE RECORDED 22-SEP-82
TIME RECORDED 16:55:53
PROJECT NUMBER V--C-3K

RUN	SAMPLE	ALPHI DEG	WA DEG	CR IN	TIMEINJ SEC	TIMECL HOUR MIN SEC MSEC	TIMEEXPT SEC
31	MSA2- 3	-1.72	18.72	26.25	3.081	16 56 19 997	162.48

M	PT PSIA	TT DEG R	T DEG R	P PSIA	Q PSIA	V FT/SEC	RHO LBM/FT3	MU LBF-SEC/FT2	RE FT-1	ITT BTU/LBM	CP BTU/LBM-DEG-R
3.93	97.05	1562.7	393.7	6.809E-01	7.36	3622.6	4.668E-03	2.994E-07	1.853E+06	3.871E+02	2.393E-01

WEDGE GARDON GAGE DATA

GAGE	X (IN)	Y (IN)	TGE (DEG R)	TW (DEG R)	QDOT (BTU/FT2-SEC)	H(TT) (BTU/FT2-SEC-R)	QDOT-O (BTU/FT2-SEC)	ST	STREX.2
1	7.50	0.00	559.9	679.0	14.11	1.511E-02	1.667E+01	3.539E-03	5.776E-02
2	9.00	0.00	558.9	671.5	13.25	1.408E-02	1.553E+01	3.298E-03	5.582E-02
3	10.50	0.00	557.8	622.2	13.76	1.463E-02	1.614E+01	3.426E-03	5.981E-02
4	12.00	0.00	559.0	615.6	13.21	1.394E-02	1.538E+01	3.265E-03	5.854E-02
5	13.50	4.50	558.6	621.4	12.39	1.317E-02	1.452E+01	3.084E-03	5.661E-02
6	13.50	3.10	557.5	616.9	11.42	1.208E-02	1.332E+01	2.829E-03	5.193E-02
7	13.50	1.75	553.0	625.7	12.48	1.332E-02	1.469E+01	3.118E-03	5.724E-02
8	13.50	0.00	558.9	617.0	13.75	1.454E-02	1.604E+01	3.405E-03	6.251E-02
9	13.50	-1.75	555.9	604.3	12.10	1.262E-02	1.392E+01	2.956E-03	5.426E-02
10	13.50	-3.10	555.7	637.8	12.63	1.365E-02	1.506E+01	3.198E-03	5.870E-02
11	13.50	-4.50	553.7	605.2	11.52	1.203E-02	1.327E+01	2.818E-03	5.173E-02

ORIGINAL PAGE IS
OF POOR QUALITY

c. Gardon Gage Data

Sample 1. Continued

RUN

ARVIN/CAL[illegible] FIELD SERVICES, INC.
AEDC DIVIS[illegible]N
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/LMSC SRM TPS MATERIALS TEST
PAGE 1

[illegible]
TIME COMPUTE 09:14:02
DATE RECORDED 2-SEP-82
TIME RECORDED 3:29:28
PROJECT NUMBER V C 2K

RUN	SAMPLE		ALPHI DEG	WA DEG	CR IN
4	CLEAN CAL	N- 1	-0.06	17.06	16.00

M	PT PSIA	TT DEG R	T DEG R	P PSIA	Q PSIA	V FT/SEC	RHO LBM/FT3	MU LBF-SEC/FT2	RE FT-1	HTT BTU/LBM	CP BTU/LBM-DEGR
3.93	97.51	1856.7	475.5	6.692E-01	7.23	4199.2	3.798E-03	3.492E-07	1.420E+06	4.664E+02	2.395E-01

T/C	X (IN.)	Y (IN.)	TW (DEG R)	QDOT (BTU/FT2-SEC)	H(TT) (BTU/FT2-SEC-R)	QDOT-O (BTU/FT2-SEC)	THICK (IN.)	ST	STREX.2
1	15.000	0.000	589.4	15.4339	1.216E-02	17.0104	0.062	3.1879E-03	5.6666E-02
2	16.000	0.000	589.9	14.9436	1.160E-02	16.4755	0.062	3.0876E-03	5.5597E-02
3	17.000	0.000	589.3	14.5537	1.146E-02	16.0382	0.062	3.0057E-03	5.4781E-02
4	18.000	0.000	589.4	13.9791	1.103E-02	15.4068	0.062	2.8873E-03	5.3230E-02
5	19.000	0.000	591.3	14.1874	1.121E-02	15.6591	0.062	2.9346E-03	5.4669E-02
6	20.000	0.000	591.1	14.1583	1.119E-02	15.6255	0.062	2.9283E-03	5.5135E-02
7	21.000	0.000	590.2	13.4480	1.062E-02	14.8303	0.062	2.7793E-03	5.2842E-02
8	22.000	0.000	590.8	13.4698	1.064E-02	14.8616	0.062	2.7852E-03	5.3448E-02
9	22.500	0.000	589.9	13.0083	1.027E-02	14.3400	0.062	2.6874E-03	5.1805E-02
10	23.000	0.000	590.6	13.0721	1.033E-02	14.4207	0.062	2.7025E-03	5.2326E-02
11	23.500	0.000	589.5	12.8295	1.012E-02	14.1409	0.062	2.6501E-03	5.1532E-02
12	24.000	0.000	590.8	12.8213	1.013E-02	14.1462	0.062	2.6511E-03	5.1769E-02
13	24.500	0.000	591.1	12.6848	1.002E-02	13.9983	0.062	2.6234E-03	5.1439E-02
14	25.000	0.000	592.5	13.1554	1.041E-02	14.5340	0.062	2.7238E-03	5.3624E-02
15	25.500	0.000	593.5	13.2358	1.048E-02	14.6344	0.062	2.7426E-03	5.4209E-02
16	26.000	0.000	591.4	12.5226	9.897E-03	13.8233	0.062	2.5906E-03	5.1403E-02
17	26.500	0.000	592.7	12.9011	1.021E-02	14.2553	0.062	2.6715E-03	5.3212E-02
18	27.000	0.000	592.0	12.5333	9.910E-03	13.8416	0.062	2.5940E-03	5.1862E-02
19	27.500	0.000	591.8	12.7545	1.008E-02	14.0838	0.062	2.6394E-03	5.2963E-02
20	28.000	0.000	592.3	12.4927	9.881E-03	13.7996	0.062	2.5862E-03	5.2082E-02
21	28.500	0.000	589.6	12.2661	9.681E-03	13.5208	0.062	2.5339E-03	5.1210E-02
22	29.000	0.000	591.3	12.3681	9.774E-03	13.6510	0.062	2.5583E-03	5.1863E-02
23	29.500	0.000	591.7	12.2720	9.702E-03	13.5499	0.062	2.5393E-03	5.1676E-02
24	30.000	0.000	591.3	12.0992	9.562E-03	13.3548	0.062	2.5028E-03	5.1103E-02
25	31.000	0.000	592.2	12.0361	9.518E-03	13.2940	0.062	2.4914E-03	5.1205E-02
26	32.000	0.000	590.6	12.1069	9.563E-03	13.3558	0.062	2.5030E-03	5.1771E-02
27	33.000	0.000	591.9	11.8519	9.371E-03	13.0879	0.062	2.4528E-03	5.1046E-02
28	21.200	-2.000	589.3	13.6073	1.074E-02	14.9952	0.062	2.8102E-03	5.3531E-02
29	22.200	-2.000	589.7	13.3766	1.056E-02	14.7476	0.062	2.7638E-03	5.3135E-02
30	23.200	-2.000	590.0	13.0761	1.032E-02	14.4182	0.062	2.7021E-03	5.2406E-02
31	24.200	-2.000	590.9	13.0646	1.032E-02	14.4162	0.062	2.7017E-03	5.2845E-02
32	25.200	-2.000	592.2	13.0743	1.034E-02	14.4414	0.062	2.7064E-03	5.3367E-02
33	26.200	-2.000	590.8	12.9393	1.022E-02	14.2758	0.062	2.6754E-03	5.3167E-02
34	27.200	-2.000	589.9	12.4683	9.842E-03	13.7467	0.062	2.5762E-03	5.1582E-02
35	28.200	-2.000	590.0	12.2436	9.666E-03	13.5003	0.062	2.5300E-03	5.1025E-02
36	29.200	-2.000	589.8	12.0557	9.516E-03	13.2912	0.062	2.4909E-03	5.0586E-02
37	30.200	-2.000	590.0	11.9046	9.399E-03	13.1269	0.062	2.4601E-03	5.0298E-02
38	21.700	-4.200	584.1	12.7978	1.006E-02	14.0455	0.063	2.6322E-03	5.0375E-02

d. Thin Skin Data

Sample 1. Concluded

ORIGINAL PAGE IS
OF POOR QUALITY

ARVIN/CALSPAN FIELD SERVICES, INC.
AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/LMSC SRB TPS MATERIALS TEST
PAGE 2

DATE COMPUTED 18-OCT-82
TIME COMPUTED 14:32:02
DATE RECORDED 22-SEP-82
TIME RECORDED 16:55:53
PROJECT NUMBER V--C-2K

ORIGINAL PAGE IS
OF POOR QUALITY

RUN	SAMPLE	ALPHI DEG	WA DEG	CR IN	TIMEINJ SEC	TIMECL HOUR	TIMECL MIN	TIMECL SEC	TIMECL MSEC	TIMEEXPT SEC
31	MSA2- 3	-1.72	18.72	26.25	3.081	16	56	19	997	162.48

M	PT PSIA	TT DEG R	T DEG R	P PSIA	Q PSIA	V FT/SEC	RHO LBM/FT3	MU LBF-SEC/FT2	RE FT-1	ITT BTU/LBM	CP BTU/LBM-DEG-R
3.93	97.05	1562.7	393.7	6.809E-01	7.36	3822.6	4.668E-03	2.994E-07	1.853E+06	3.871E+02	2.393E-01

CAMERA	PIC NO.	TIME SEC	TIMEEXP SEC	TS 1 DEG R	TS 2 DEG R	TS 3 DEG R	TS 4 DEG R	TP DEG R
TOP	16	56.25	54.52	541.1	538.2	541.1	537.5	534.0
OS	17	60.00	58.27	542.4	539.3	542.6	538.5	534.0
TOP	17	60.01	58.28	542.3	539.0	542.5	538.5	533.9
IR	7	63.56	61.83	543.5	540.3	543.9	539.4	533.9
OS	18	63.76	62.03	543.9	540.1	544.3	539.6	533.9
TOP	18	63.77	62.04	544.0	540.4	544.2	539.5	534.2
SHG	2	65.67	63.94	544.2	540.7	544.7	540.0	534.0
OS	19	67.52	65.79	545.0	541.5	545.2	540.6	534.0
TOP	19	67.54	65.81	545.2	541.6	545.3	540.6	534.1
OS	20	71.28	69.55	546.2	542.8	546.5	541.5	534.1
TOP	20	71.30	69.57	546.5	542.6	546.7	541.7	534.2
IR	8	73.49	71.76	547.2	543.4	547.4	542.2	534.1
OS	21	75.04	73.31	548.0	544.0	548.2	542.6	534.2
TOP	21	75.05	73.32	548.0	543.9	548.0	542.9	534.0
OS	22	78.80	77.07	549.5	545.4	549.5	544.1	534.1
TOP	22	78.81	77.08	549.5	545.4	549.3	544.1	534.1
TOP	23	82.56	80.83	550.4	546.7	550.6	545.4	534.2
OS	23	82.56	80.83	550.4	546.7	550.6	545.4	534.2
IR	9	83.40	81.67	551.0	547.2	550.8	545.4	534.3
TOP	24	86.32	84.59	552.1	548.3	551.7	546.4	534.2
OS	24	86.32	84.59	552.1	548.3	551.7	546.4	534.2
OS	25	90.06	88.33	553.2	549.8	553.0	547.8	534.4
TOP	25	90.08	88.35	553.2	549.6	553.2	548.1	534.2
IR	10	91.32	91.59	554.3	550.9	554.2	549.1	534.6
OS	26	93.82	92.10	554.8	551.3	554.3	549.4	534.4
TOP	26	93.84	92.11	554.6	551.3	554.5	549.4	534.5
TOP	27	97.59	95.86	556.1	552.7	555.9	550.8	534.6
OS	27	97.59	95.86	556.1	552.7	555.9	550.8	534.6
OS	28	101.35	99.62	557.3	554.3	556.9	552.2	534.6
TOP	28	101.36	99.63	557.5	554.2	557.1	552.2	534.6
IR	11	103.24	101.51	558.2	554.9	557.5	552.8	534.9
TOP	29	105.11	103.38	559.0	555.9	558.5	553.8	534.7
OS	29	105.11	103.38	559.0	555.9	558.5	553.8	534.7
TOP	30	108.85	107.12	560.1	557.1	559.9	555.2	534.8
OS	30	108.85	107.12	560.1	557.1	559.9	555.2	534.8
TOP	31	112.61	110.88	561.6	558.5	561.0	556.8	534.8
OS	31	112.61	110.88	561.6	558.5	561.0	556.8	534.8
IR	12	113.16	111.43	561.4	558.8	561.0	556.8	534.9

Sample 2. Photographic Data

AEDC DIVISION
ARVIN/CALSPAN FIELD SERVICES, INC.
VON KARMAN GAS DYNAMICS FACILITY (VKF)
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/LMSC SRB TPS TEST
PROJECT V4 C-2K

DATE COMPUTED 2-NOV-82
TIME COMPUTED 16:37
DATE RECORDED 2-SEP-82
TIME RECORDED 7:48:

RUN	SAMPLE		WA	TIMEINJ	TIMECL
23	IF	2	6.65	2.716	7 48 25 200

M	PT PSIA	TT DEG R	T DEG R	P PSIA	Q PSIA	V FT/SEC	RHO LBM/FT3	MU LBM-SEC/FT2	RE FT-1
3.93	97.2	1899.6	487.8	0.6648E+00	7.16	4252.8	0.367E-02	0.356E-06	0.136E+07

MODEL EMISSIVITY 0.90

IR TEMPERATURE RECORD -- TW/TT
TIME EXP 2.198 SEC

RUN 23 FRAME 1 PAGE 1

*** POINT ***

LINE	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
60	0.358	0.459	0.546	0.555	0.554	0.558	0.554	0.552	0.567	0.576	0.583	0.590	0.578	0.580	0.584	0.583	0.588	0.593	0.598	0.596
61	0.362	0.471	0.560	0.554	0.561	0.567	0.563	0.550	0.559	0.581	0.589	0.582	0.578	0.580	0.570	0.595	0.595	0.592	0.599	0.600
62	0.368	0.483	0.556	0.557	0.590	0.583	0.557	0.539	0.572	0.590	0.591	0.587	0.583	0.585	0.585	0.592	0.593	0.596	0.601	0.604
63	0.365	0.493	0.558	0.573	0.601	0.581	0.566	0.564	0.585	0.602	0.599	0.585	0.596	0.592	0.588	0.599	0.599	0.601	0.600	0.603
64	0.368	0.497	0.565	0.574	0.581	0.561	0.558	0.573	0.581	0.590	0.585	0.581	0.594	0.601	0.596	0.596	0.595	0.599	0.598	0.607
65	0.377	0.491	0.552	0.561	0.561	0.564	0.567	0.569	0.575	0.581	0.591	0.586	0.576	0.592	0.592	0.597	0.601	0.602	0.601	0.599
66	0.377	0.495	0.554	0.569	0.579	0.562	0.557	0.568	0.578	0.584	0.592	0.593	0.592	0.601	0.593	0.592	0.597	0.599	0.600	0.598
67	0.377	0.463	0.542	0.578	0.593	0.576	0.563	0.569	0.581	0.589	0.598	0.601	0.585	0.600	0.586	0.593	0.602	0.599	0.595	0.602
68	0.383	0.474	0.546	0.573	0.582	0.571	0.571	0.591	0.583	0.586	0.596	0.596	0.595	0.588	0.596	0.592	0.596	0.605	0.601	0.593
69	0.392	0.460	0.546	0.571	0.561	0.569	0.576	0.586	0.576	0.587	0.600	0.598	0.595	0.593	0.598	0.598	0.600	0.598	0.597	0.592
70	0.394	0.474	0.559	0.570	0.574	0.561	0.582	0.590	0.591	0.591	0.594	0.570	0.583	0.609	0.601	0.602	0.592	0.589	0.593	0.603
71	0.396	0.490	0.568	0.572	0.570	0.550	0.574	0.592	0.601	0.593	0.581	0.562	0.574	0.601	0.604	0.607	0.599	0.591	0.595	0.595
72	0.390	0.497	0.567	0.560	0.548	0.551	0.579	0.595	0.597	0.600	0.598	0.588	0.581	0.577	0.594	0.602	0.596	0.588	0.568	0.595
73	0.396	0.510	0.555	0.555	0.563	0.567	0.568	0.595	0.596	0.596	0.596	0.588	0.592	0.595	0.592	0.595	0.598	0.592	0.594	0.601
74	0.394	0.489	0.550	0.559	0.579	0.579	0.587	0.586	0.595	0.591	0.596	0.598	0.603	0.602	0.605	0.598	0.593	0.596	0.602	0.606
75	0.396	0.484	0.549	0.559	0.583	0.585	0.570	0.557	0.588	0.593	0.594	0.595	0.606	0.597	0.603	0.601	0.595	0.600	0.600	0.598
76	0.392	0.451	0.538	0.554	0.570	0.574	0.557	0.563	0.579	0.589	0.599	0.599	0.600	0.597	0.601	0.594	0.598	0.595	0.599	0.600
77	0.385	0.484	0.532	0.557	0.575	0.584	0.573	0.579	0.577	0.586	0.575	0.582	0.595	0.601	0.601	0.600	0.599	0.597	0.599	0.601
78	0.380	0.473	0.546	0.563	0.570	0.580	0.558	0.565	0.560	0.592	0.584	0.593	0.587	0.583	0.582	0.597	0.602	0.592	0.599	0.606
79	0.371	0.474	0.561	0.571	0.566	0.580	0.574	0.564	0.579	0.582	0.569	0.589	0.598	0.596	0.587	0.592	0.596	0.598	0.607	0.612
80	0.371	0.491	0.553	0.548	0.579	0.597	0.599	0.585	0.565	0.570	0.594	0.595	0.598	0.598	0.593	0.593	0.593	0.597	0.599	0.602
81	0.371	0.467	0.534	0.557	0.591	0.592	0.594	0.583	0.571	0.581	0.580	0.577	0.593	0.596	0.594	0.594	0.604	0.594	0.588	0.594
82	0.374	0.442	0.527	0.567	0.553	0.561	0.589	0.581	0.564	0.588	0.580	0.590	0.592	0.592	0.593	0.595	0.591	0.594	0.599	0.599
83	0.354	0.452	0.526	0.538	0.548	0.556	0.559	0.574	0.581	0.568	0.572	0.572	0.578	0.585	0.578	0.573	0.581	0.580	0.587	0.577
84	0.340	0.394	0.483	0.522	0.530	0.523	0.528	0.536	0.532	0.535	0.533	0.521	0.522	0.528	0.527	0.511	0.514	0.530	0.539	0.523
85	0.328	0.345	0.358	0.362	0.368	0.368	0.374	0.374	0.371	0.374	0.377	0.374	0.360	0.377	0.380	0.377	0.383	0.374	0.380	0.380
86	0.335	0.345	0.340	0.350	0.340	0.350	0.354	0.350	0.350	0.358	0.354	0.358	0.354	0.354	0.365	0.358	0.362	0.362	0.365	0.362

Sample 3. IR Data